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# COMPUTER SIMULATION OF THE PROBABILITY THAT ENDANGERED WHALES WILL INTERACT WITH OIL SPILLS

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## Abstract

A numerical model system was developed to assess quantitatively the probability that endangered bowhead and gray whales will encounter spilled oil in Alaskan waters. Bowhead and gray whale migration and diving-surfacing models, and an oil spill trajectory model comprise the system. The migration models were developed from conceptual considerations, then calibrated with and tested against observations. The distribution of animals is represented in space and time by discrete points, each of which may represent one or more whales. The movement of a whale point is governed by a random walk algorithm which stochastically follows a migratory pathway. The stochastic diving-surfacing models are used to compute surfacing behavior sequences for each species. The oil spill model, developed under a series of other contracts, accounts for transport and spreading behavior in open water and in the presence of sea ice. Historical wind records and heavy, normal, or light ice cover data sets are selected at random to provide stochastic oil spill scenarios for whale-oil interaction simulations.

## STUDY TEAM

Eric L. Anderson is a systems analyst and numerical modeler with Applied Science Associates, Inc. (ASA). He assisted with the oil spill modeling tasks for this project.

Ann E. Bowles is a marine biologist and data analyst with Hubbs Marine Research Institute (HMRI) of San Diego. She was responsible for marine mammal data collation, analysis, and interpretation, and prepared the Markov matrices for the diving-surfacing models.

Teri Highling is office manager at ASA. She was responsible for word processing and report preparation.

Katherine Jayko is a numerical modeler and ocean engineer with ASA. Her M.S. thesis (1982) focused on orthonormal function analyses of seawater density data. She performed the majority of the numerical modeling for the project.

Stephen Leatherwood of HMRI is a specialist in marine mammal distribution, life history and abundance. He has published widely in the field, including a Handbook of Whales and Dolphins, published by Sierra Club (1983).

Mark Reed, project manager, is a physical and biological systems modeler with ASA. He completed his Ph.D. in Ocean Engineering at the University of Rhode Island in 1980 with a thesis on oil spill fishery impact assessment modeling.

Malcolm L. Spaulding is president of ASA and a professor of Ocean Engineering at the University of Rhode Island. He specializes in the numerical modeling of physical processes in the marine environment.

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## EXECUTIVE SUMMARY

The numerical model system described in this report was developed to quantitatively assess the probability that endangered bowhead and gray whales will encounter spilled oil in Alaskan waters. Bowhead and gray whale migration models, a diving-surfacing model, and an oil spill trajectory model comprise the system. The migration models rely on whale sighting data, ensembled for all years on record, to define mean migration pathways. Distances traveled over 3 to 6 months, divided by the travel time, were used to estimate mean migratory speeds over appropriate sections of the migration route. Stochastic velocity components were then added such that maximum instantaneous swimming speeds did not exceed those observed. Modeled whale densities were then compared with field estimates at various times and locations, as available, and mean migration speeds were adjusted to calibrate the model. The distribution of animals is represented in space and time by discrete points, each of which may represent one or more whales. The movement of a whale point is governed by a random walk algorithm which stochastically follows a migratory pathway. The stochastic diving-surfacing models were used to compute surfacing behavior sequences for each species. The oil spill model, developed under a series of other contracts, accounts for transport and spreading behavior in open water and in the presence of sea ice. Historical wind records and heavy, normal, or light ice cover data sets were selected at random to provide stochastic oil spill scenarios for whale-oil interaction simulations.

A whale - oil spill interaction simulation consists of running one of the migratory whale models using one spill scenario from the oil spill model output to dynamically define surface oil coverage. For any whale point which traverses the water column covered by an oil slick, the diving-surfacing model is used to compute a number of interactions or encounters. Probability distributions of whale - oil encounters are produced by combining the results of simulations for one site in a planning area. Using the conditional probability distribution for oil spills occurring in that area, total probability distributions can also be produced.

Sensitivity studies were performed to assess the extent to which model output variability is related to specific model system parameters or components. The results of these studies can be summarized as follows:

(1) as the number of discrete points used to represent the population increases, the mean total exposure time (i.e., total time whales are within the bounds of an oil slick) stabilizes;

(2) the variability of the exposure time estimate due to the stochastic components of the migration model exceeds that

due to number of discrete points at about 500 points;

(3) a timestep exceeding the 3 hour timestep used to run the oil spill model results in erroneous estimates of whale-oil interactions;

(4) the dive time model contributes only a small fraction of the total variability of the interaction estimates;

(5) 25 randomly selected scenarios at one spill site and one season are sufficient to avoid bias in the results due to inter-annual variability;

(6) inter-annual variability in weather scenarios, and therefore the difference between one oil spill trajectory and another, represents the major source of variability in whale-oil spill interaction estimates.

The models were applied to 5 launch points within each of 4 Alaskan OCS planning areas: Navarin Basin, Beaufort Sea, Chukchi Sea and St. George Basin (Figure 1). Twenty-five different trajectories were simulated from each launch point for one or more seasons, using stochastically selected winds from historical wind records, Table 1 shows the number of spill scenarios which resulted in whale-oil interactions for each site and season.

In the Navarin Basin planning area simulations, only bowhead whales encountered oil. A spill occurring near St. Matthew Island, where approximately one-third of the bowhead population was assumed to spend the months of November to April, posed the greatest potential for impacting bowhead whales.

The spill scenarios at all 5 sites investigated in the Beaufort Sea planning area resulted in the oiling of an average of 1-5% of the bowhead population. It should be noted that these spills were timed to occur when bowhead whales were known to be present; seasons for occurrence were not selected at random. Spills at the Beaufort sites located near Pt. Barrow could be encountered by a small percentage (less than 0.2%) of gray whales utilizing the Alaskan Chukchi Sea for feeding in the summer.

Spills in the Chukchi Sea planning area have the potential of impacting both bowhead and gray whales. Oil which is released in the spring and becomes trapped by ice may impact both species if it persists in the area until gray whales arrive. During simulated oil spill scenarios from the 5 Chukchi sites, maximums of 1.5% of the bowhead whales and 1.4% of the gray whales encountered oil.

Spills in the St. George Basin planning area will probably have no impact on bowhead whales. Only simulated spills occurring in Unimak Pass resulted in gray whales encountering oil, with an average of about 3% of the population surfacing in oil. Gray whales are only

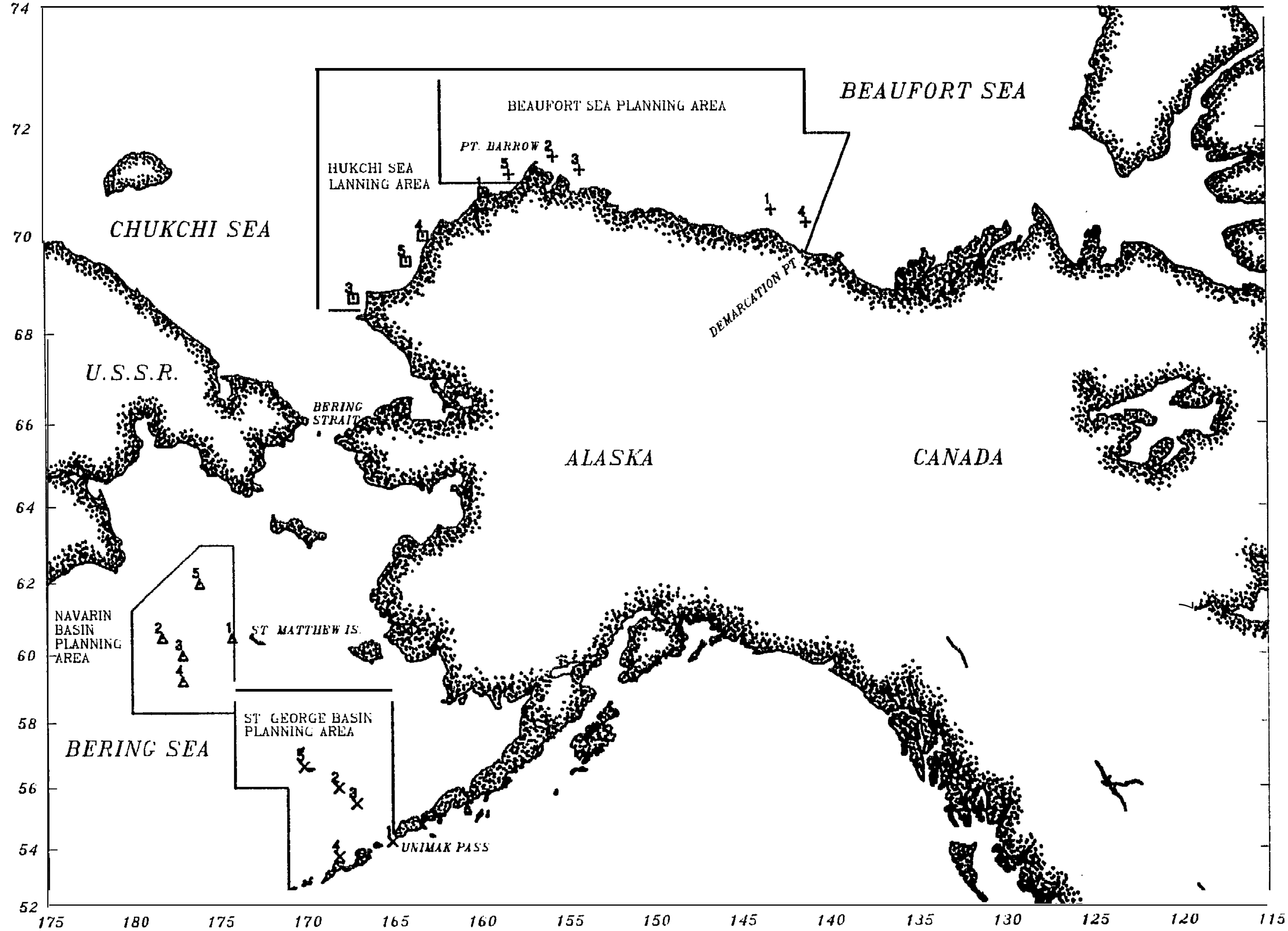



Figure 1. Location of planning areas and spill sites within each area.

Table 1. Number of spill scenarios resulting in whale-oil interactions by planning area. Twenty-five scenarios were simulated for each species, site and season.

| Planning Area | Spill Site | Season | Bowhead | Gray |
|---|---|---|---|---|
| Navarin | 1 | Feb 1 - May 31 | 19 | 0 |
| | 2 | May 1 - Nov 30 | 0 | 0 |
| | 3 | May 1 - Nov 30 | 0 | 0 |
| | 4 | Feb 1 - May 31 | 1 | 0 |
| | 5 | May 1 - Ott 31 | 0 | 0 |
| Beaufort | 1 | Aug 1 - Ott 31 | 17 | 0 |
| | 2 | Apr 1 - Jun 30 | 10 | 1 |
| | 2 | Aug 1 - Ott 31 | 17 | 0 |
| | 3 | Aug 1 - Ott 31 | 16 | 0 |
| | 4 | Aug 1 - Ott 31 | 15 | 0 |
| | 5 | Apr 1 - Jun 30 | 5 | 1 |
| | 5 | Aug 1 - Ott 31 | 10 | 5 |
| Chukchi | 1 | Apr 1 - Jun 1 | 10 | 0 |
| | 1 | Jun 30 - Ott 31 | 8 | 8 |
| | 2 | Aug 1 - Ott 31 | 6 | 0 |
| | 3 | Mar 1 - Jun 1 | 10 | 4 |
| | 3 | Jun 30 - Ott 31 | 0 | 8 |
| | 4 | Jun 1 - Ott 31 | 4 | 16 |
| | 5 | Ott 2 - Jan 30 | 0 | 19 |
| | 5 | Jun 1 - Ott 1 | 3 | 8 |
| St. George | 1 | Mar 1 - Jun 30 | 0 | 12 |
| | 1 | Aug 1 - Dec 31 | 0 | 7 |
| | 2 | May 1 - Ott 31 | 0 | 0 |
| | 3 | May 1 - Ott 31 | 0 | 0 |
| | 4 | May 1 - Ott 31 | 0 | 0 |
| | 4 | Nov 1 - May 31 | 0 | 0 |
| | 5 | Apr 1 - Nov 30 | 0 | 0 |

present in the Pass from April through early June and November through December as they enter and leave the Bering Sea, so only spills occurring during these time windows hold the potential for whale-oil interactions.

Total probability estimates based on results of this study will be biased towards high whale-oil interaction probabilities, as discussed in detail in Section 9. However, total encounter probabilities have been estimated for the Beaufort Sea planning area to exemplify the methodology. Total probabilities for bowhead and gray whales encountering oil spilled in the Beaufort Sea were calculated to be approximately 57% and 6%, respectively, assuming the mean number of spills occurring is 1.63. The high probability of bowhead whales encountering oil, despite a low number of expected spills, results from spills at all sites contacting whales. For bowhead whales there is greater than an 83% probability that 20 or fewer of every 100,000 surfacings occurring during an oil spill will be in oil. For gray whales there is approximately a 99% probability that 5 or fewer of every 100,000 surfacings during an oil spill event will be in oil.

## 1. Introduction

The orderly development of outer continental shelf (OCS) mineral resources is the responsibility of the United States Department of the Interior, Minerals Management Service (MMS). The MMS seeks to pursue this goal in a manner which assures protection of marine and coastal environments. In Alaskan waters, the protection of two endangered whale populations, the bowhead (*Balaena mysticetus*) and gray (*Eschrichtius robustus*) whales, is of special concern. The study described here is focused on the quantification of the probability of interactions between migrating bowhead and gray whales and potential oil spills in Alaskan OCS planning areas north of the Aleutian Islands. This quantification is achieved by applying a system of numerical models describing oil spill behavior, whale migration and diving-surfacing patterns. Figure 1-1 shows the schematic linkages among these system components, and the inputs required by each.

The oil spill model was used to produce time series of surface slick locations and areal coverage for hypothetical spills. In each planning area, 5 release sites were selected by MMS, and 25 different trajectories were simulated from each site for 1 or more seasons, using stochastically selected winds from historical wind records.

Models of migratory behavior were developed for both the bowhead and gray whale populations. The distribution of animals is represented in space and time by discrete points, each of which may represent one or more whales. The movement of a whale point is governed by a random walk algorithm which stochastically follows a migratory pathway. The diving-surfacing model is used to compute surfacing behavior sequences for each species. These models were calibrated and tested against observed whale distribution data.

A whale - oil spill interaction simulation consists of running one of the migratory whale models using one spill scenario from the oil spill model output to dynamically define surface oil coverage. For any whale point which passes through water covered by an oil slick, the diving-surfacing model is used to compute a number of surfacings in oiled waters. These surfacings constitute the whales' encounters (interactions) with oil. Total probability distributions of whale - oil encounters can be produced by combining the results of simulations for all sites in a planning area with the conditional probability distribution for oil spills occurring in that area.

The following report sections discuss the development of each model component, and application of the model system to 4 Alaskan OCS planning areas (Figure 1-2). Section 2 includes descriptions of the migrating whale modeling methodology used, and sources of data for model development and calibration. The diving-surfacing model for each species is described in Section 3. The oil spill model used here was developed previously, and is described in Section 4, while Section

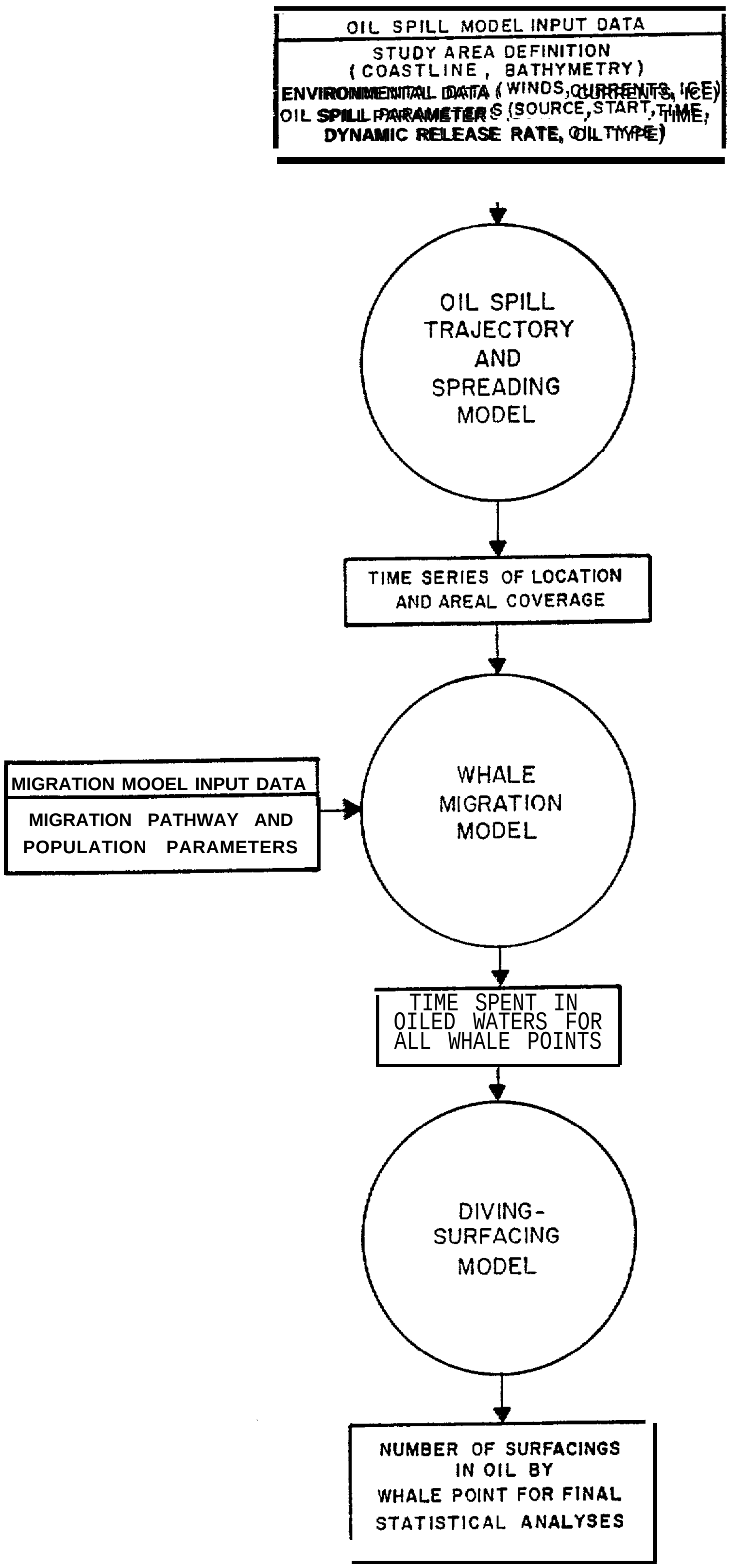



Figure 1-1. Model system schematic.

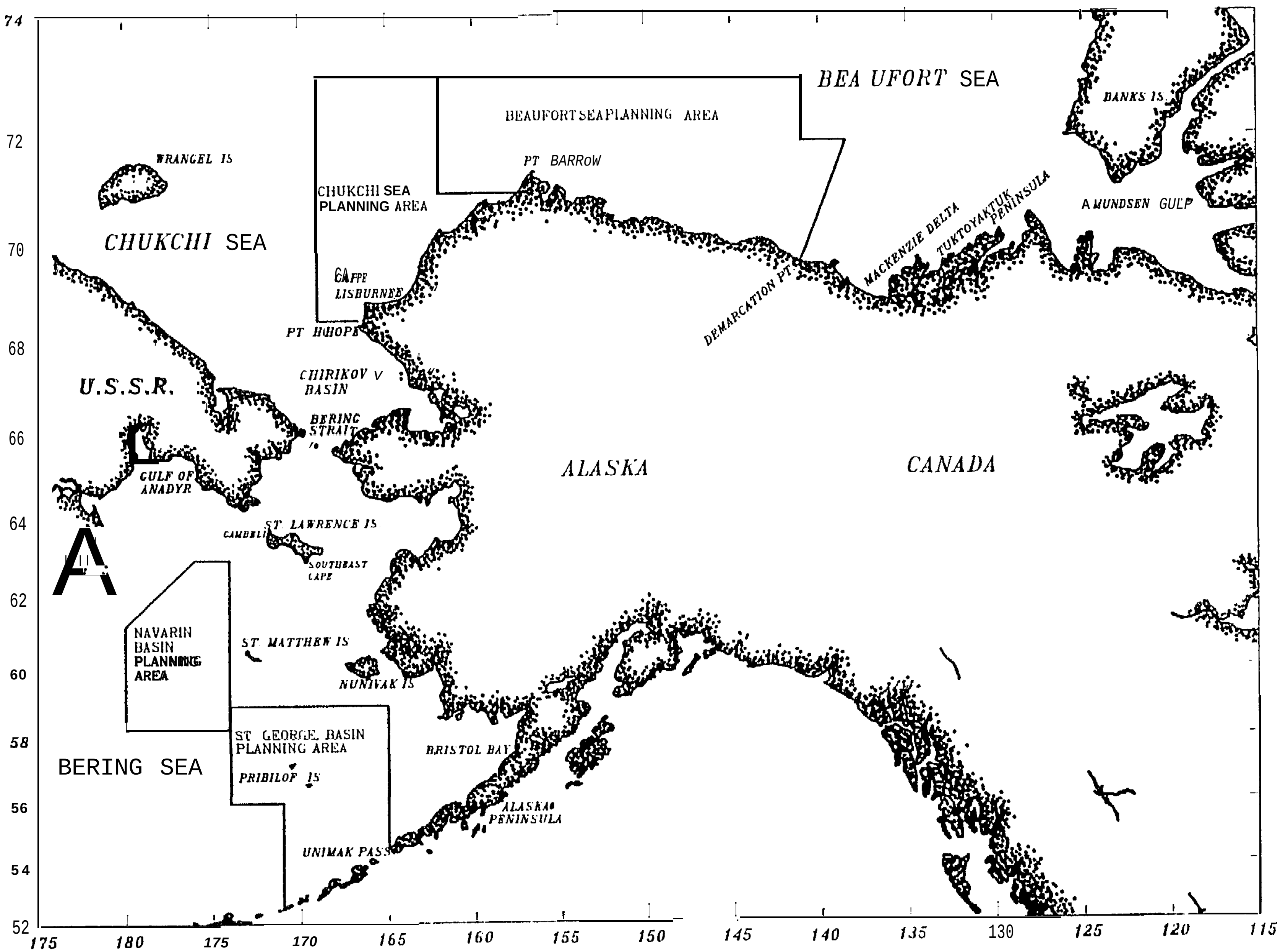



Figure 1-2. Study area, showing place names referenced in text.

5 covers linkages between the migrating whale and oil spill models. A variety of sensitivity analyses were performed prior to applications of the system, and these are presented in Section 6. Sections 7 and 8 discuss, respectively, the methodology and results of system applications to Alaskan OCS planning areas. An example set of computations of total whale-oil spill interaction probabilities, based on conditional probabilities of oil spill occurrence, is given for the Beaufort Sea planning area in Section 9.

## 2. Whale Migration Models

### 2.1 Overview of Modeling Methodology

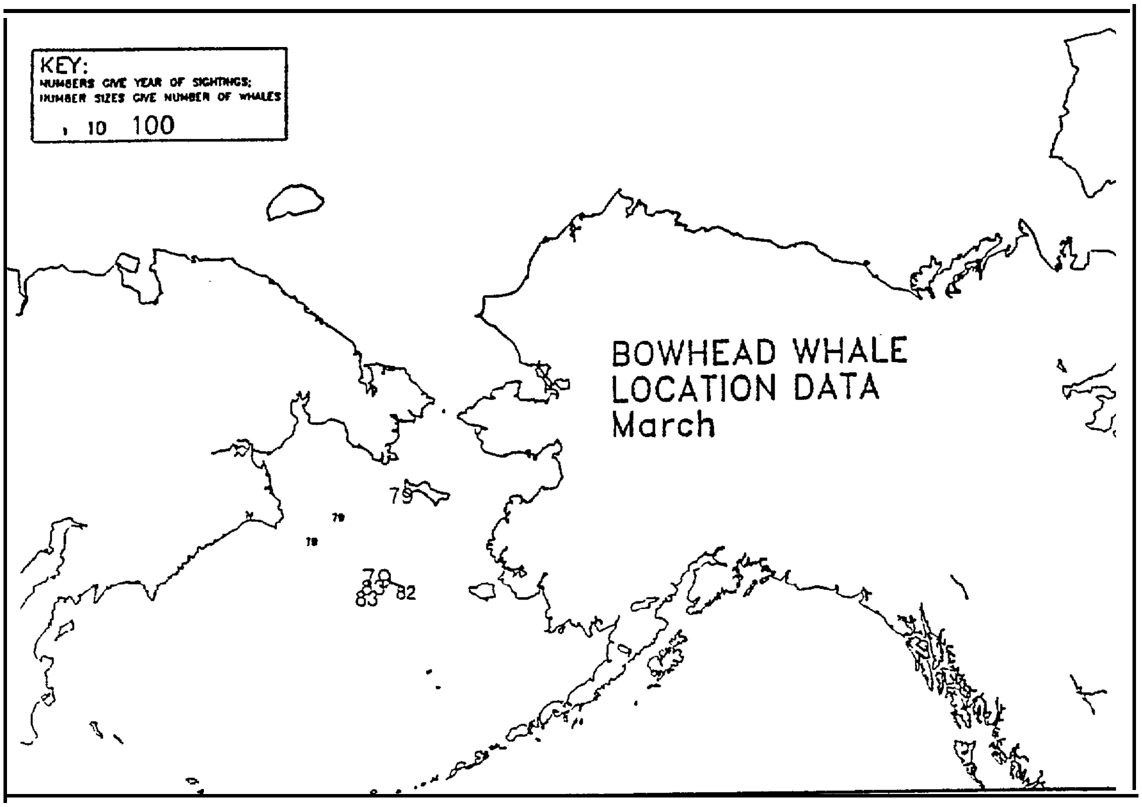
Models were developed to simulate the annual migration of bowhead and gray whales in the Bering, Chukchi and Beaufort Seas. The models rely on whale sighting data, ensembled for all years on record, to define mean migration pathways. Distances traveled over 3 to 6 months, divided by the travel time, were used to estimate mean migratory speeds over appropriate sections of the migration route. Stochastic velocity components were then added such that maximum instantaneous swimming speeds did not exceed those observed. Modeled whale densities were compared with field estimates at various times and locations, as available, and mean migration speeds were adjusted to calibrate the model. The underlying data base is described in detail in Reed et al (1984).

Simulation of whale movement is accomplished by translating a number of points along a defined migration path, subject to land and ice constraints. Each point represents the movement of one or several migrating whales. Random components incorporated in the swimming velocity of each whale point simulate the variability evident in the behavior of the bowhead and gray whale populations. Migration model output consists of the location of each whale point at time intervals specified by the user. A variety of other data products (e.g., densities, mean headings) can then be produced from this raw output.

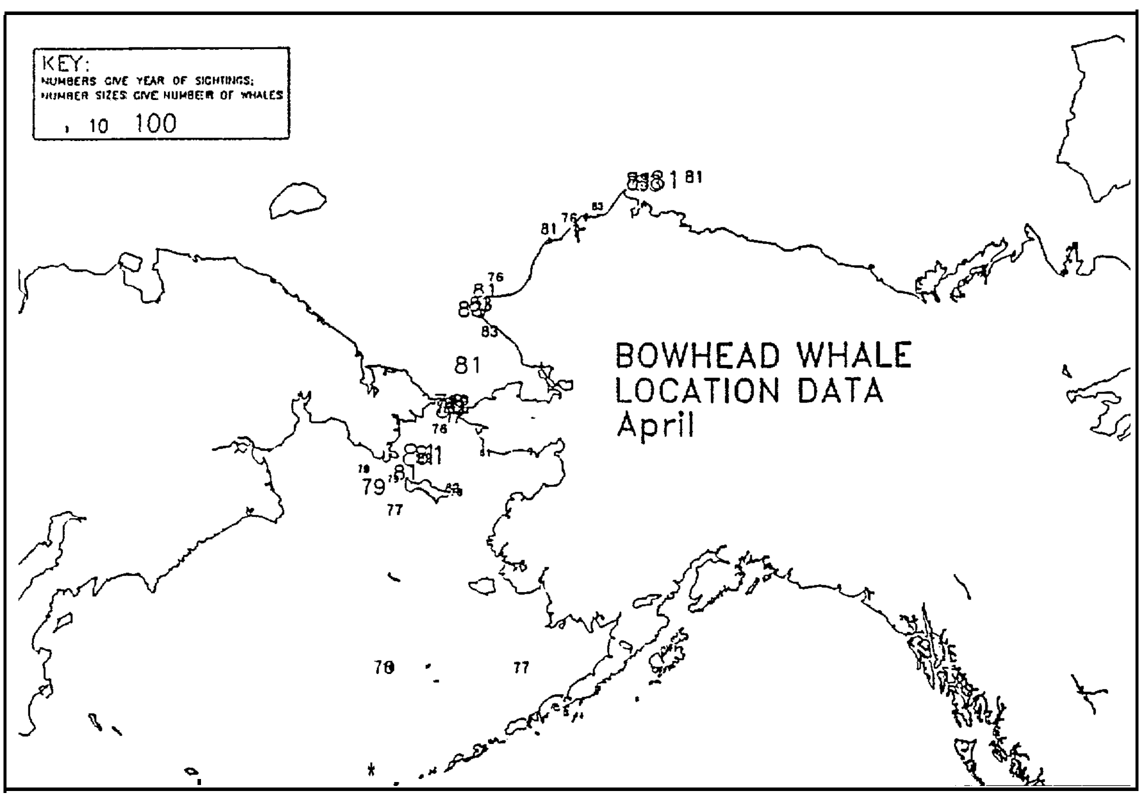
When coupled to the oil spill model (Figure 1-1), model output includes probability histograms of whale-oil spill interactions. An interaction is defined as a single surfacing of a whale within the boundary of an oil slick. The number of interactions between a whale and an oil slick is therefore a function of the diving-surfacing behavior of the whale during the time it remains within an oiled area. Diving-surfacing behavior sequences are simulated stochastically, based on observations. It is assumed that diving - surfacing and migrational behaviors are unaltered by the presence of oil, Hypotheses regarding behavioral changes, such as avoidance, can be incorporated into the model to estimate possible effects on numbers and durations of interactions.

### 2.2 Bowhead Whale Model

Definition of the mean migratory pathways of the bowhead whale governs the movement and distribution of simulated whales. To determine these pathways, the bowhead whale sighting data, summarized in Figures 2-la through 2-lb (from Reed et al, 1984) were first divided into “northbound” (March - July) and “southbound” (August - October) data sets. Polynomials were fit by least squares

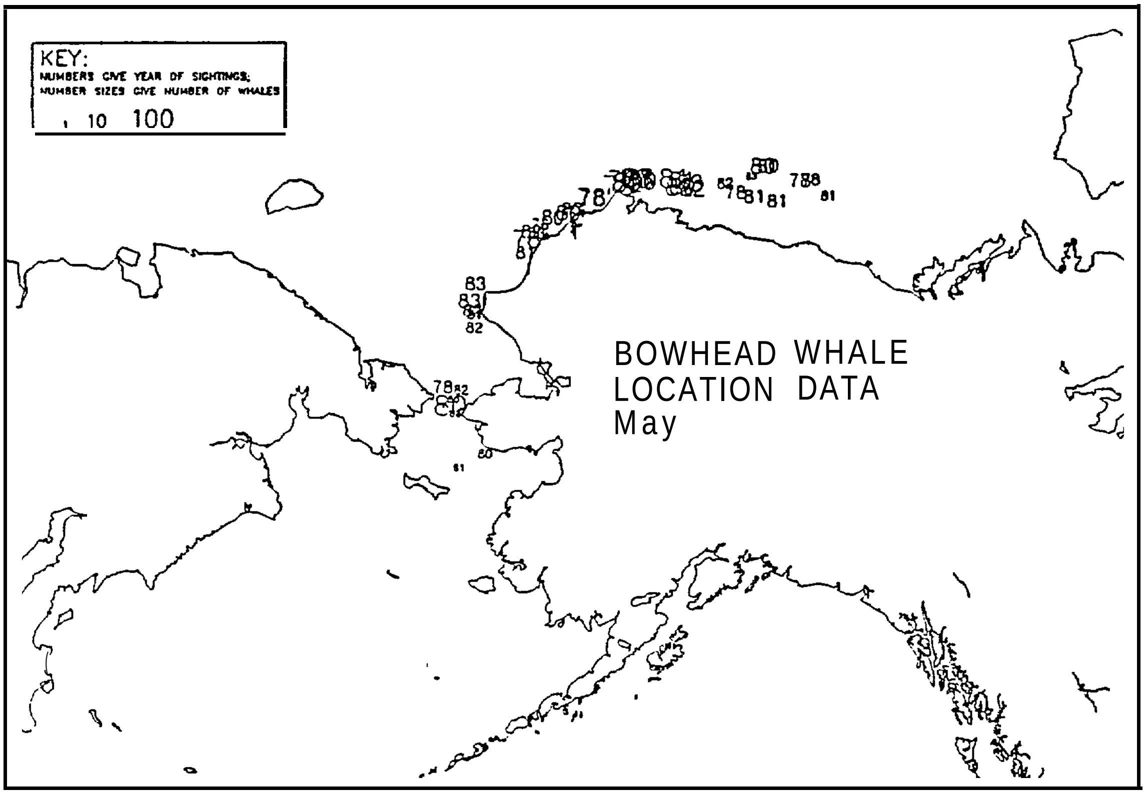



(a)




(b)

Figure 2-la,b. Bowhead whale sighting data in a) March and b) April.

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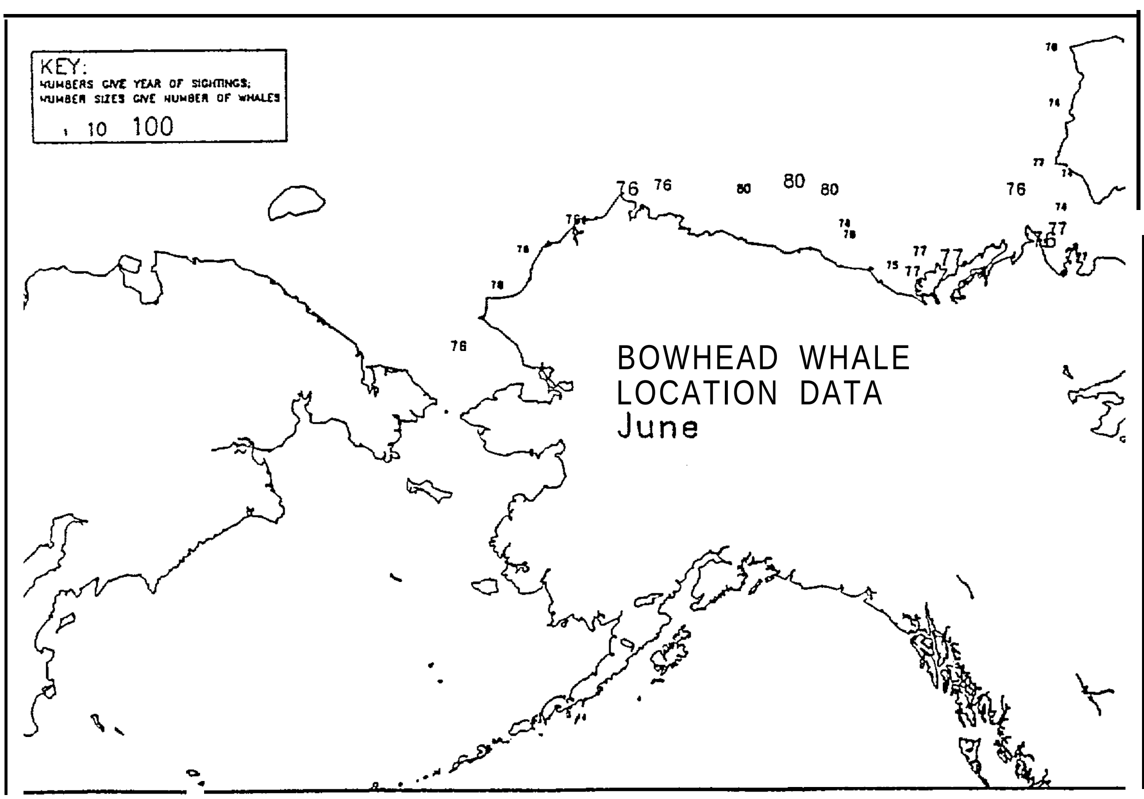
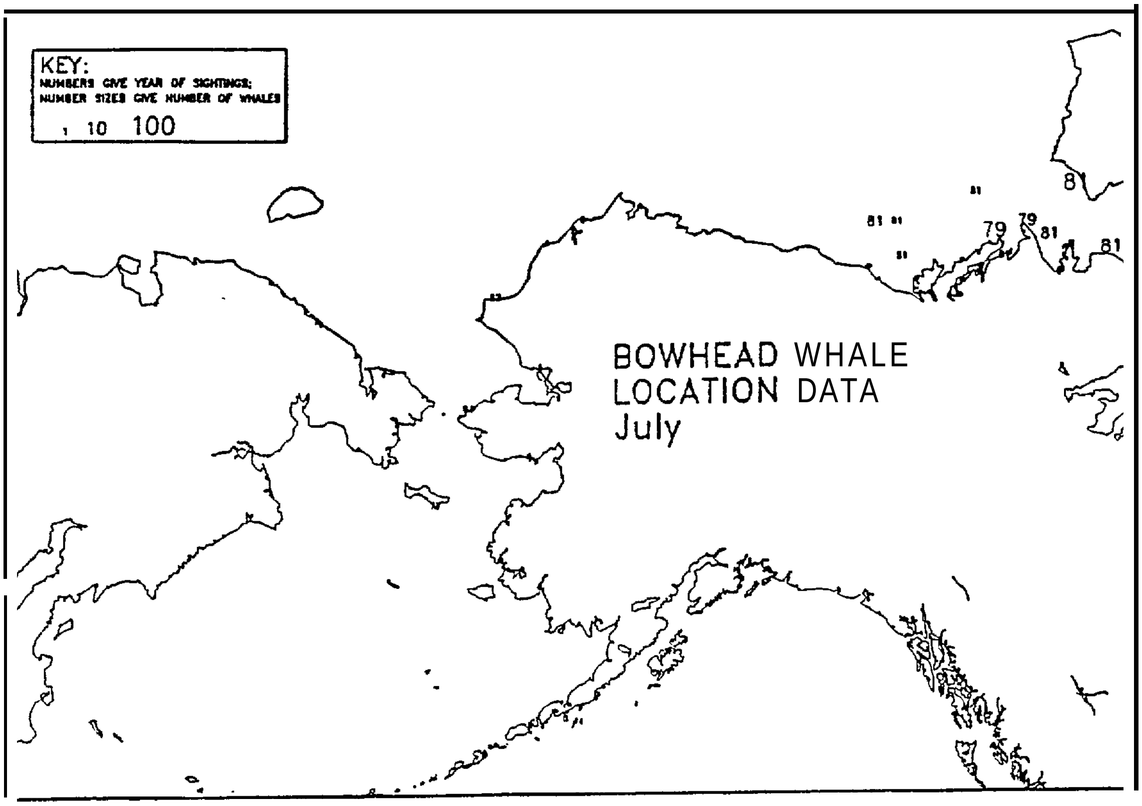



(d)

Figure 2-1c, d. Bowhead whale sighting data in c) May and d) June.

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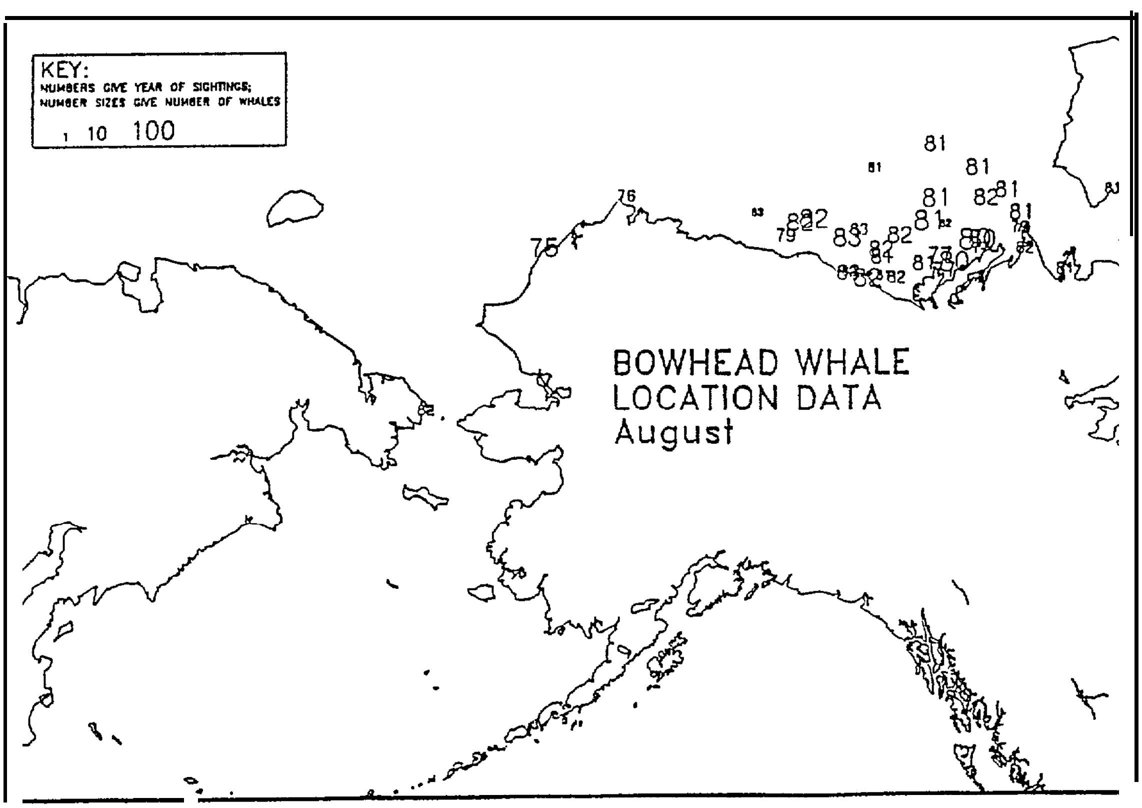
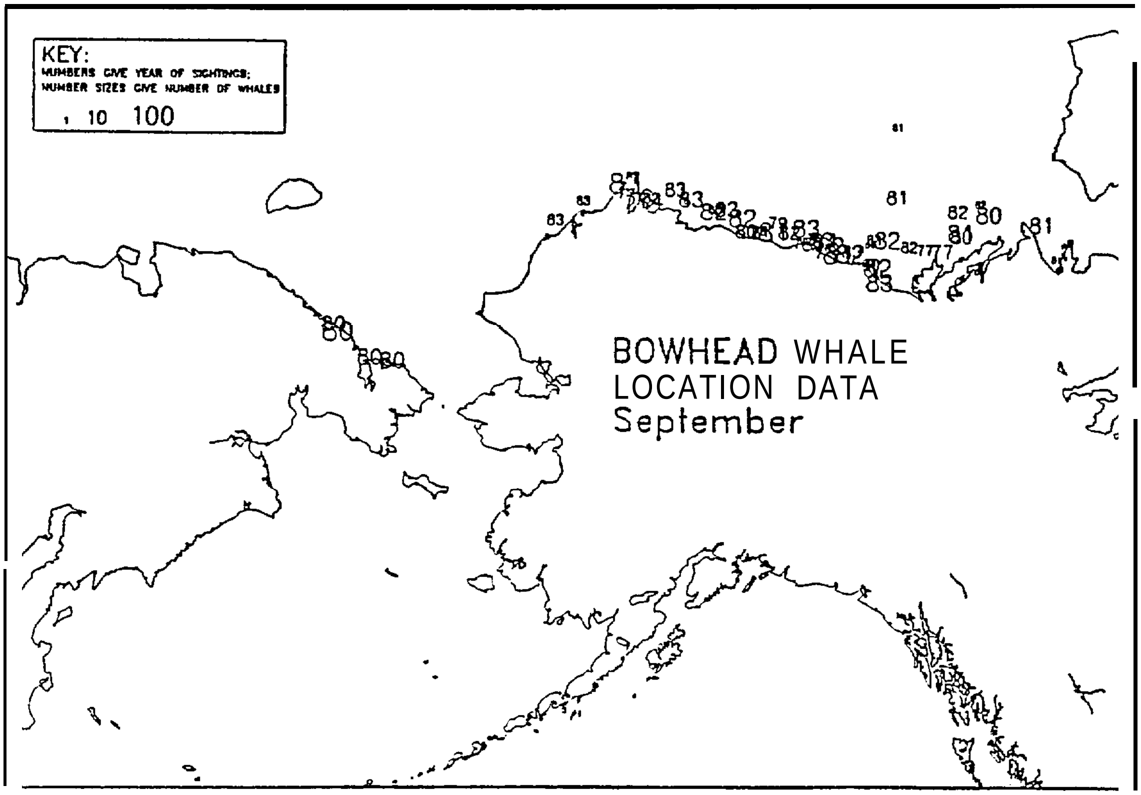
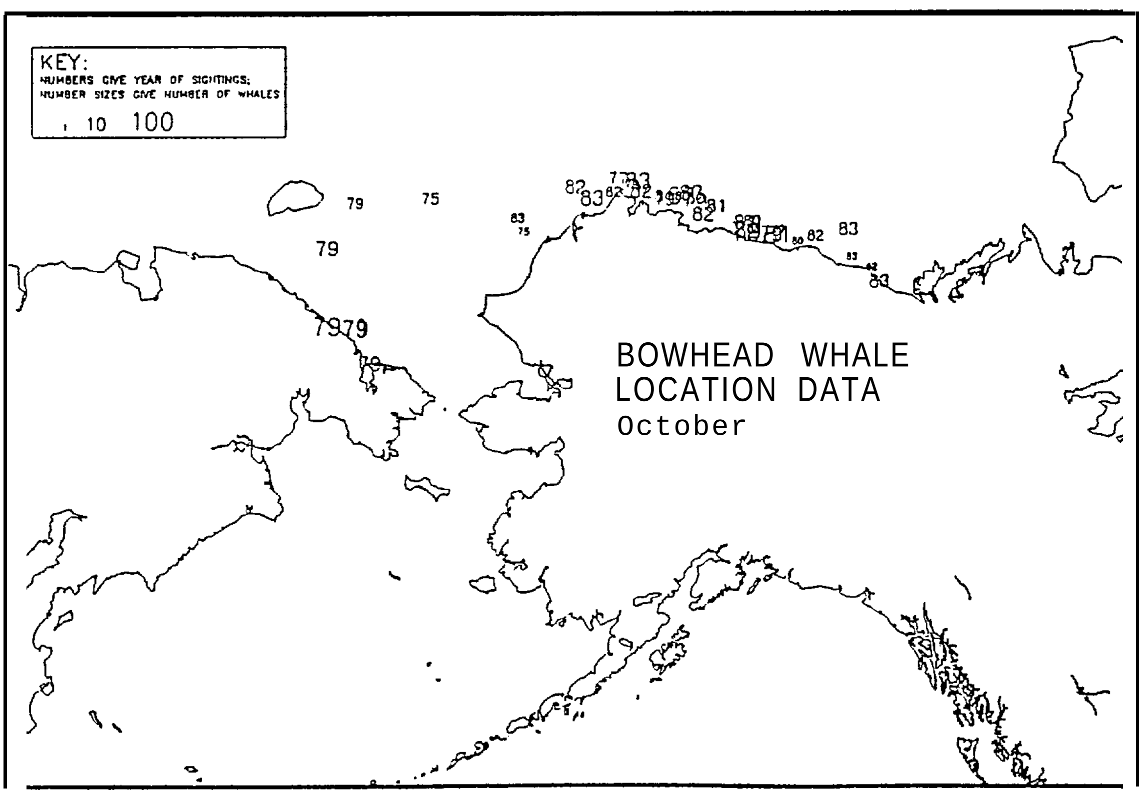



(f)

Figure 2-1e,f. Bowhead whale sighting data in e) July and f) August.




(g)




(h)

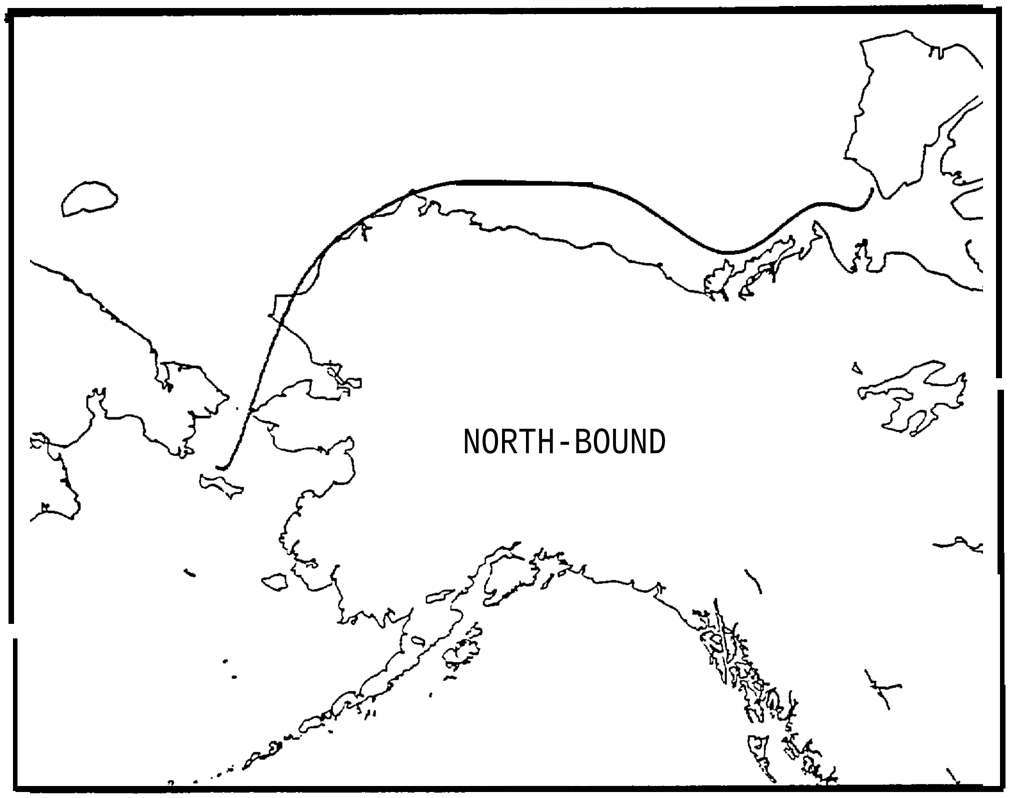
Figure 2-1g, h. Bowhead whale sighting data in g) September and h) October.

to each data set. Because September and October data include whale sightings on both the Soviet and Alaskan coasts of the Chukchi Sea, the latter data set was further subdivided across the international dateline. Polynomials were then fit by least squares to each data set. The northbound curve (Figure 2-2a) was then corrected for land crossings, and connected to 3 hypothesized overwintering areas in the Gulf of Anadyr, and south of St. Lawrence and St. Matthew Islands (Braham et al, 1984). These are regions in which polynyas (areas of persistent open water) are known to form each winter. Curves A and B (Figure 2-2b) for southbound animals were connected across the Chukchi Sea. North and southbound curves were linked at both ends, and a migratory loop was added in the Beaufort Sea to allow early arrivals to head northeast toward Banks Island through the extensive system of leads, or open water channels in the ice cover, typically appearing there in early spring (Braham et al, 1980b; Marko and Fraker, 1981). Discrete points, termed "attractor" points, were then specified along the resulting migratory path (Figure 2-3). Attractor points are used to compute directional bearings for whale points as they are moved during a simulation. Simulated whales thus move toward successive attractor points along the migration route. For comparison, the migration route suggested by Richardson (1983) is shown in Figure 2-4.

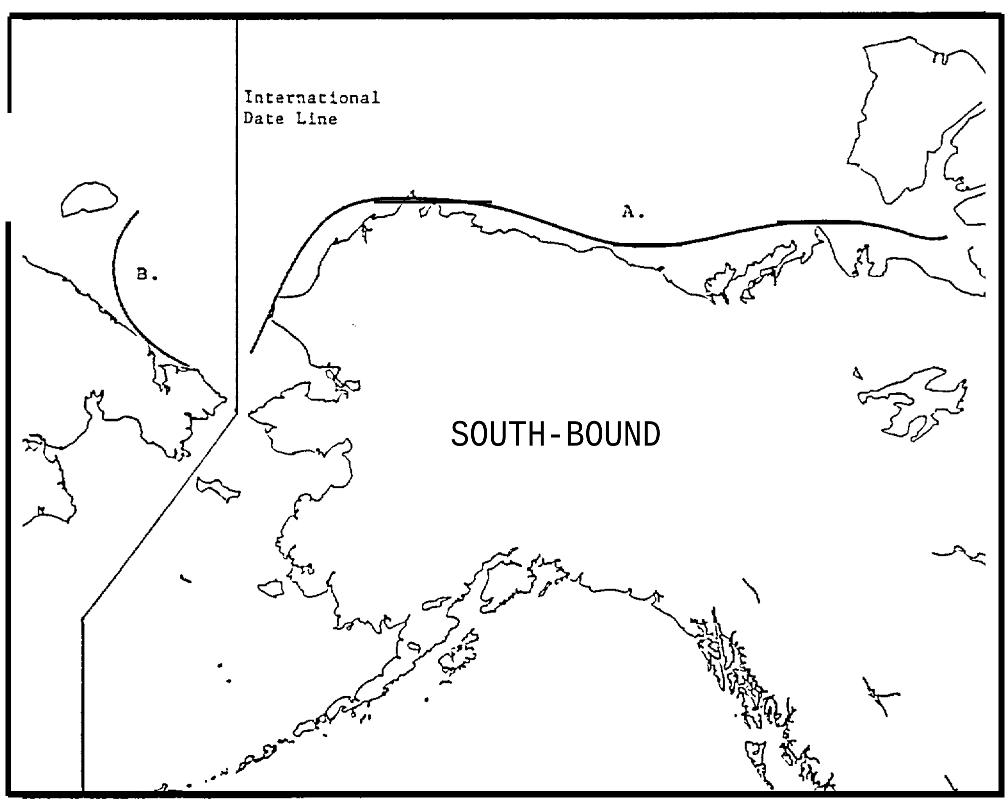
The positions of the attractor points along the migratory path are dictated only by the degree of control required to move the whales in the model. In areas where the whales generally follow a narrow, well-defined route (e.g., the northbound migration from Cape Lisburne to Pt. Barrow) or where movement is constrained by land masses (e.g., around St. Lawrence Island), close spacing of the attractor points is necessary to control the direction of movement. Areas in which the migration corridor is wide and poorly-defined (e.g., crossing the Chukchi Sea in the autumn) require only enough attractor points to define the general direction of movement. Preliminary model runs were used to determine areas in which greater resolution was required, and the number and spacing of attractor points were adjusted as necessary.

The minimum spacing between attractor points and the maximum speed at which a whale can swim dictate the maximum model timestep. The model timestep is variable, but for simple migrational modeling 12 hours provides adequate resolution of whale movement. For simulation of cetacean interactions with oil spills, a shorter timestep is necessary to achieve the greater resolution of movement needed to realistically assess the duration and frequency of interactions.

The simulated bowhead whale migration is further controlled by defining each attractor point as one of three types. Pass points direct the whale to the next sequential attractor point once the whale has come within a specified radius of the first




(a)




(b)

Figure 2-2. Least squares polynomial fit to bowhead whale sighting data for a) March - July data, and b) August - October data. (A: data east of date line only; B: data west of date line only.)

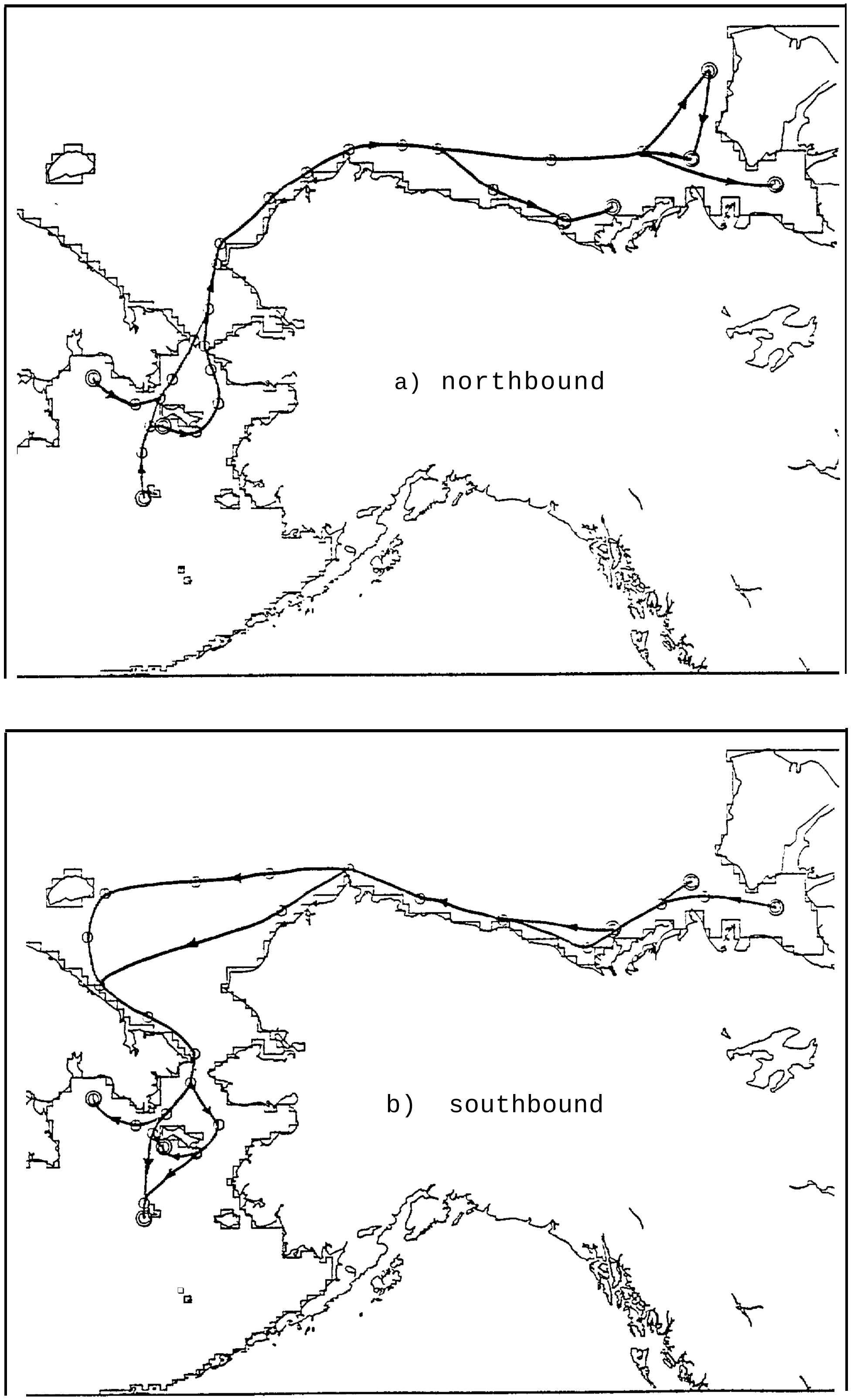



Figure 2-3. Mean pathways for simulated bowhead whale migration, showing location of attractor points and model grid. Hold points are shown with a double ring.

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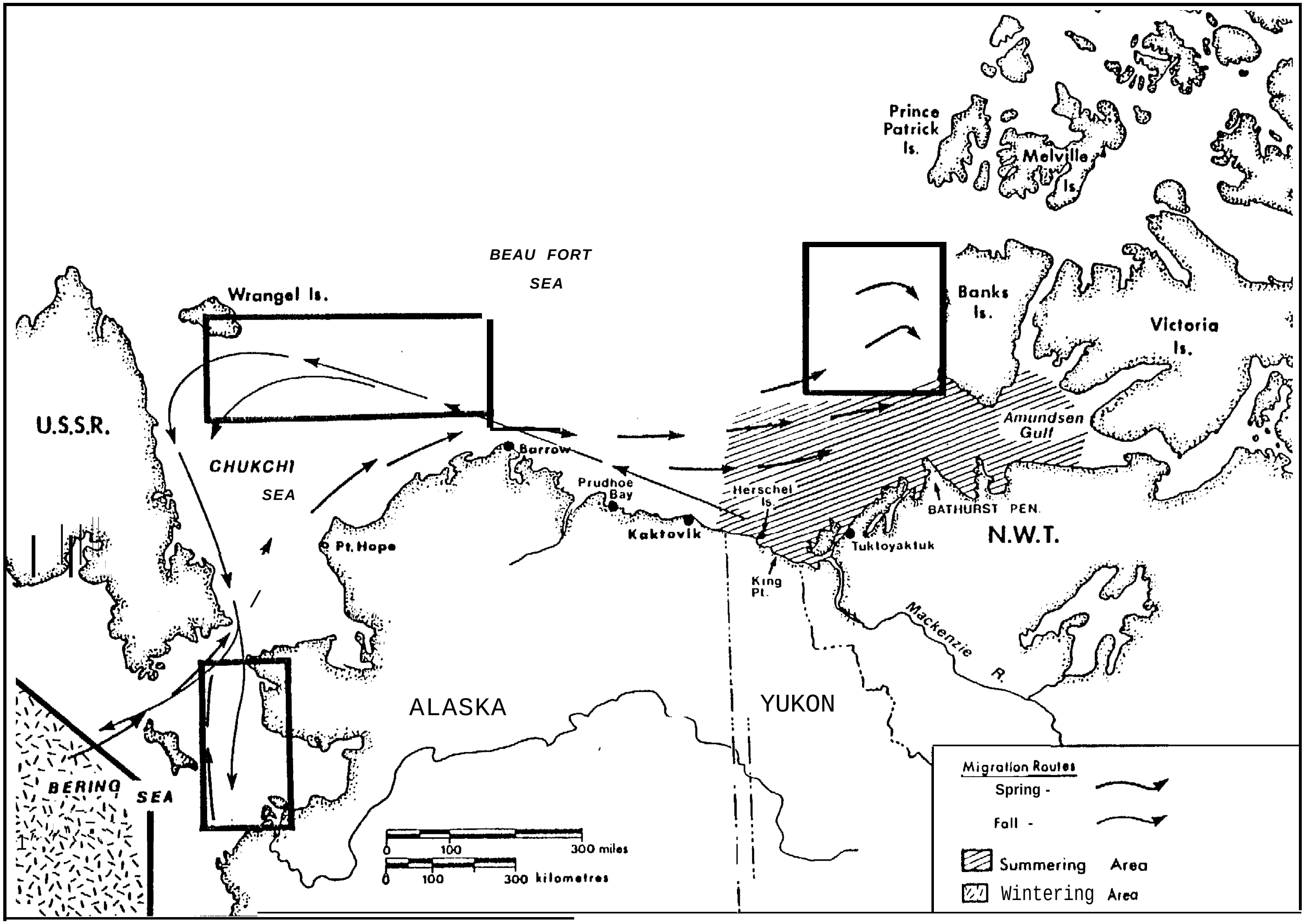


Figure 2-4. Bowhead whale migratory pattern inferred from observations (from Richardson, 1983). Rectangular boxes indicate those areas for which supporting data are lacking.

point. Branch points allow whales to take alternate pathways at certain locations. Associated with each branch point are possible alternate routes to be followed, the probability of a whale taking each route, and the first and last days each route is open for travel. This latter factor distributes the population among areas in which bowhead whales have been observed, and can be used to simulate closure of certain pathways by heavy ice. For example, a branch point allows different migration routes east across the Beaufort Sea, depending on whether a whale arrives in the early or late stages of the spring migration. Hold points constrain the whales to move within a set radius of the point until a specified day, after which they proceed to the next attractor. Hold points are used to control the summer feeding and winter movement of the whales. The winter activities of bowhead whales are not well known. Therefore we simulate the animals as remaining in the vicinity of the 3 polynyas where they are known to be at the beginning of the winter season.

To move whales between attractor points, each point (representing a single whale or a group of whales) is assigned a velocity vector V. This velocity vector is composed of three components: $V_1$, $V_2$, and $V_3$ (Figure 2-5). The magnitude of VI is the mean estimated swimming speed of a whale in a given geographic region at a given time of year (Table 2-l). The direction of VI is defined parallel to the line connecting the attractor point the whale has just left with the one toward which it is heading. $V_2$ is a random component parallel to VI , in either the same or the opposite direction, reflecting observed variability in swimming speeds. $V_3$ is a second random component perpendicular to $V_1$, varying in magnitude according to the observed dispersion of bowhead whales. Thus $V_3$ is relatively small during the northward migration in spring, but relatively large (i.e., on the order of $V_1$ ) during feeding in summer. The net velocity magnitude $|V|$ is subject to the limitation that it must be less than or equal to a maximum sustainable swimming speed, which varies by season and geographical region (Table 2-l). During a timestep of duration At, each whale point is translated a distance $|V|$ * At in the direction of V, subject to land and ice boundaries. If a boundary is encountered, new values of $V_2$ and $V_3$, and a new displacement are computed until a valid move is defined.

Ice cover dynamics are modeled deterministically based on climatic data (Brewer et al, 1977; NOAA, 1984; LaBelle et al, 1983) . Because bowhead whales navigate through heavy ice (Braham et al, 1984; Braham et al, 1980b; Marko and Fraker, 1981), only ice cove r exceeding 9/10 concentration was considered potentially sufficient to restrict their movements; the 9/10 ice edge was therefore inc lude d in the bowhead whale model. During simulations, the ice edge location is updated at biweekly intervals. At default, the model allows bowhead whales to migrate through any degree of ice coverage, although the 9/10 concentration may optionally be specified as limiting. Thus ice cover is inn-limiting

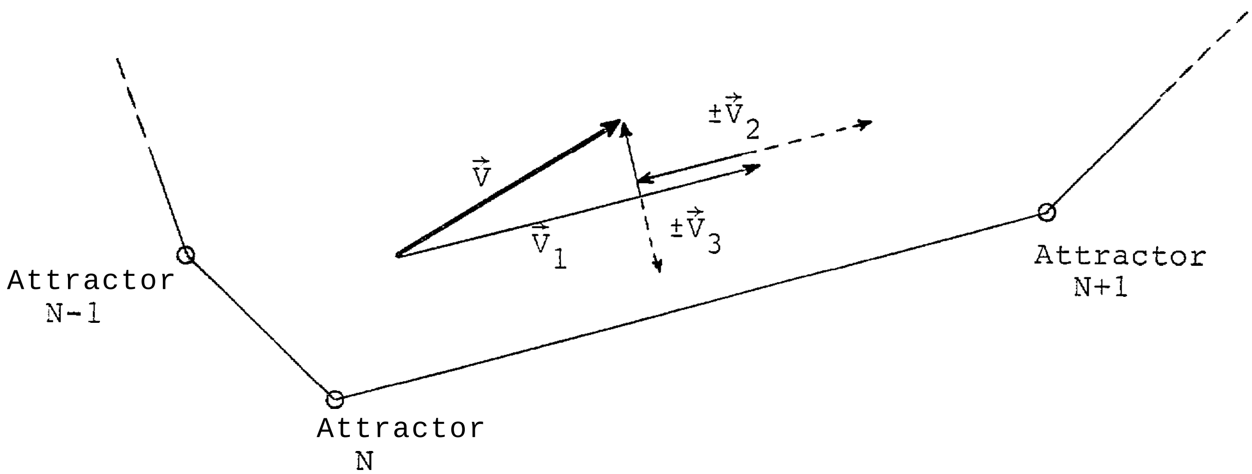


Figure 2-5. Instantaneous components of a migratory whale's velocity. $\vec{V}_1$, parallel to the migration route, has a magnitude estimated from Table 2-1. $\vec{V}_2$ is a random component, also parallel to the migration route. $\vec{V}_3$ is a second random component, perpendicular to $\vec{V}_1$ and $\vec{V}_2$.

Table 2-1. Observed, estimated, and modeled bowhead whale swimming speeds.

| SEASON | LOCATION | SPEED (km/hr) | REFERENCE |
|---|---|---|---|
| | | **OBSERVED** | |
| Spring | Beaufort | 3.1 ± 2.7 | Braham et al, 1980b |
| Spring | Beaufort | 4.7 ± 0.6 | Rugh and Cubbage, 1980 |
| Summer | Beaufort | 1.25 (a) | Davis et al, 1983 |
| Summer | Beaufort | 4.7 ± 1.9 | Wursig et al, 1982 |
| Autumn | Beaufort | 4.9 ± 1.4 | Koski and Davis, 1980 |
| Autumn | Beaufort | 2,8 - 5.6 | Ljungblad, 1981 |
| | | **ESTIMATED** | |
| Spring (April-July) | St. Lawrence Banks Island | 0.8 - 1.1 (b) | |
| Autumn (August-October) | Banks Island to St. Lawrence Island | 1.4 (c) | |
| | | **MODELED** | |
| Spring | Bering Sea | 1.4 ± 0.7 | |
| Spring | Chukchi | 1.8 ± 0.8 | |
| Spring | Beaufort | 1.1 ± 0.5 | |
| Summer | Beaufort | 1.1 ± 0.5 | |
| Autumn | Chukchi-Bering | 1.4 ± 0.7 | |

(a) This observation is for "speed-made-good" , or the net displacement of a whale over several hours, divided by the total time between the first and last sightings.

(b) Mean migratory speed for the spring migration is estimated by dividing the total distance from St. Lawrence Island to Banks Island (i.e., 2300 km) by the approximate time of travel (i.e., 3-4 months).

(c) Mean migratory speed for the autumn migration is estimated by dividing the total distance from Banks Island to St. Lawrence Island via the Siberian Coast by the approximate travel time (i.e., 3 months).

for bowhead whale movements as simulated here. Ice cover is modeled on a 0.5 degree longitude, 0.25 degree latitude grid. Leads and polynyas (perennial open water areas), which are generally sub-gridscale phenomena, may be accounted for by allowing specific attractor points to control whale migration, over-riding ice cover specified at the larger grid scale. In this way, whales can be allowed to migrate through cells in which the general ice cover exceeds the limiting concentration, but in which leads are known to exist during certain seasons. Additionally, whales can be delayed at specified attractor points during simulation of a heavy ice year. Movements of bowhead whales are not restricted by ice cover in the simulations reported here.

Tne initial geographic distribution of the population must be specified to simulate the bowhead whale annual migration. A primary simulation is begun in the winter, when it is assumed that all bowhead whales are moving within their wintering areas. The total population is randomly distributed throughout these areas. Once an annua 1 simulation has been run, the model can be initialized at any day of the year from the simulated distributions stored on magnetic disk.

Rather than using one point per whale, the model can be made to run faster by allowing each point to represent some larger number of whales. Comparison of model runs using 100, 500 and 1000 points to represent the bowhead whale population of 3800* whales shows no appreciable difference in calculated whale densities in different survey areas throughout the year. This is due to the large survey areas, typically greater than 10,000 $km^2$, over which density estimates are made. The simulations of migration patterns reported in this section have therefore employed 100 points, each representative of 38 whales. For finer scale simulations, such as interactions with oil spills, a larger number of points is necessary to adequately resolve cetacean distributions relative to the smaller oiled areas.

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*When this study began, the bowhead whale population was estimated at 3800 whales (Zeh et al, 1983). Since that time, the population estimate has been revised upward to approximately 4400 animals (Krogman et al, 1985 ins.). To be consistent with previous reports, we 'have retained the 3800 whale estimate. Since results are presented as a percentage of the population, they remain valid for any population size and the number of affected individuals in the population can easily be calculated.

All bowhead whales are released from their wintering areas on the same day to start the northward migration. This release date is specified by the user and may be different for each year of a simulation. In this marine r, the effects of heavy and light ice years on the timing of the northbound migration may be incorporated into the simulation. The user may also specify the first day bowhead whales may pass through Bering Strait. This serves to hold the whales south of Bering Strait until the day specified, and can be used to simulate herding of the whales and delay in the migration due to particularly heavy ice.

Upon release from the winter grounds, each whale is assigned an initial attractor point and appropriate mean heading. Once the whale comes within a specified distance of that attractor, the whale is assigned to the next attractor and given a new mean heading. In this fashion whales are roved from their wintering grounds in the Bering Sea to their summer feeding areas in the Beaufort Sea and back again. Figures 2-6a through 2-61 show snapshots of the simulated bowhead whale distribution for a "typical" year. The location of the 9/10 ice concentration boundary is shown for reference on each figure, but in this simulation the whales' movements were not restricted by ice. All bowhead whales began the northward migration on March 15, and encountered no blockage at Eering Strait. The distribution of whales agrees well with the sighting data, as summarized in Reed et al (1984). Figure 2-7 shows the progressive movements throughout the year of 10 whale points in the above simulation.

To calibrate the bowhead whale migration model, we used estimates of bowhead whale density from surveys of various areas and months, as available. When the investigators presented density estimates corrected for missed or submerged whales, these values were used in preference to those that were only effort-corrected. The corrections for missed and submerged whales increased density estimates by up to a factor of 8.

Unadjusted results of transect surveys usually underestimate the actual number of whales present in the survey area because not all whales at the surface are seen by observers (missed whales) and not all whales are at the surface (submerged whales). Environmental conditions during the survey, such as ice cover, sun glare, fog, and sea state, affect the number of missed whales, while whale behavior determines the number of submerged whales.

Corrections for missed whales are obtained by conducting experiments in which extra observers silently report whales seen, and comparisons are made between their reports and those of the survey team. The whales not seen by both teams are considered to be missed whales. For most of the corrected density estimates reported in this study (Davis et al, 1982), the missed whales are factored into the estimate as follows (assuming two observers):

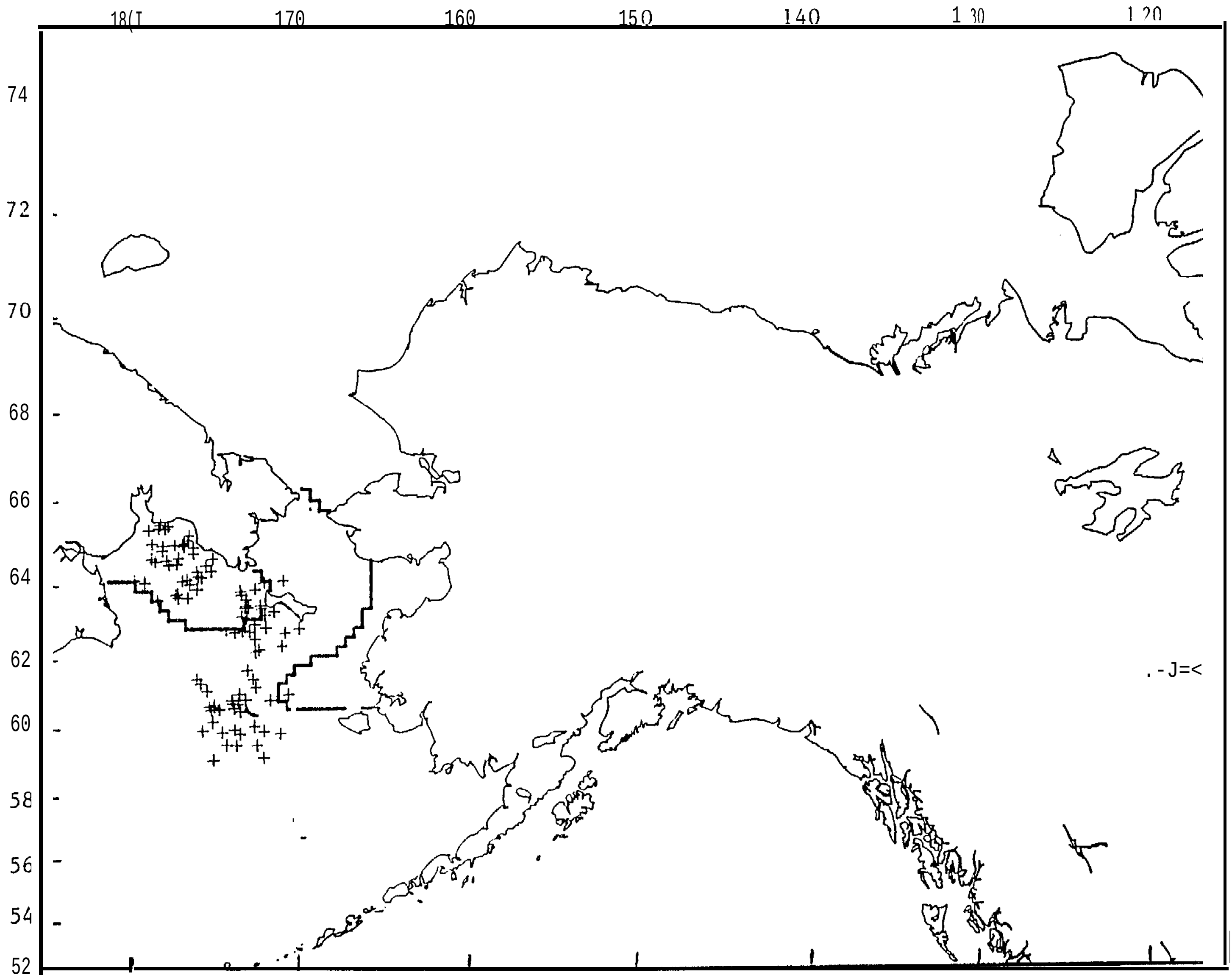



Figure 2-6a. Simulated distribution of 100 bowhead whale points on January 1. Heavy line is limit of 9/10 ice cover.

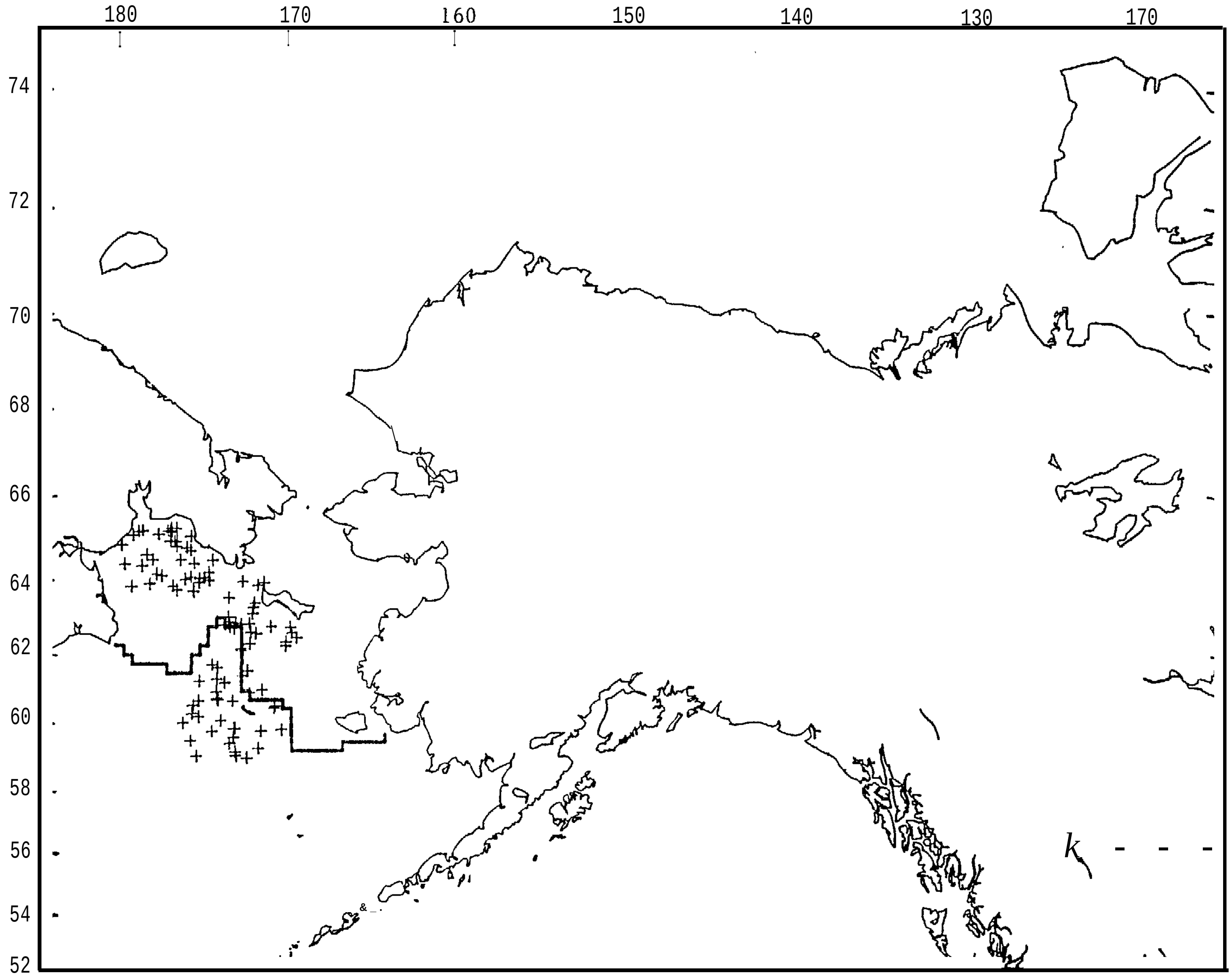



Figure 2-6b. Simulated distribution of 100 bowhead whale points on February 1. Heavy line is limit of 9/10 ice cover.

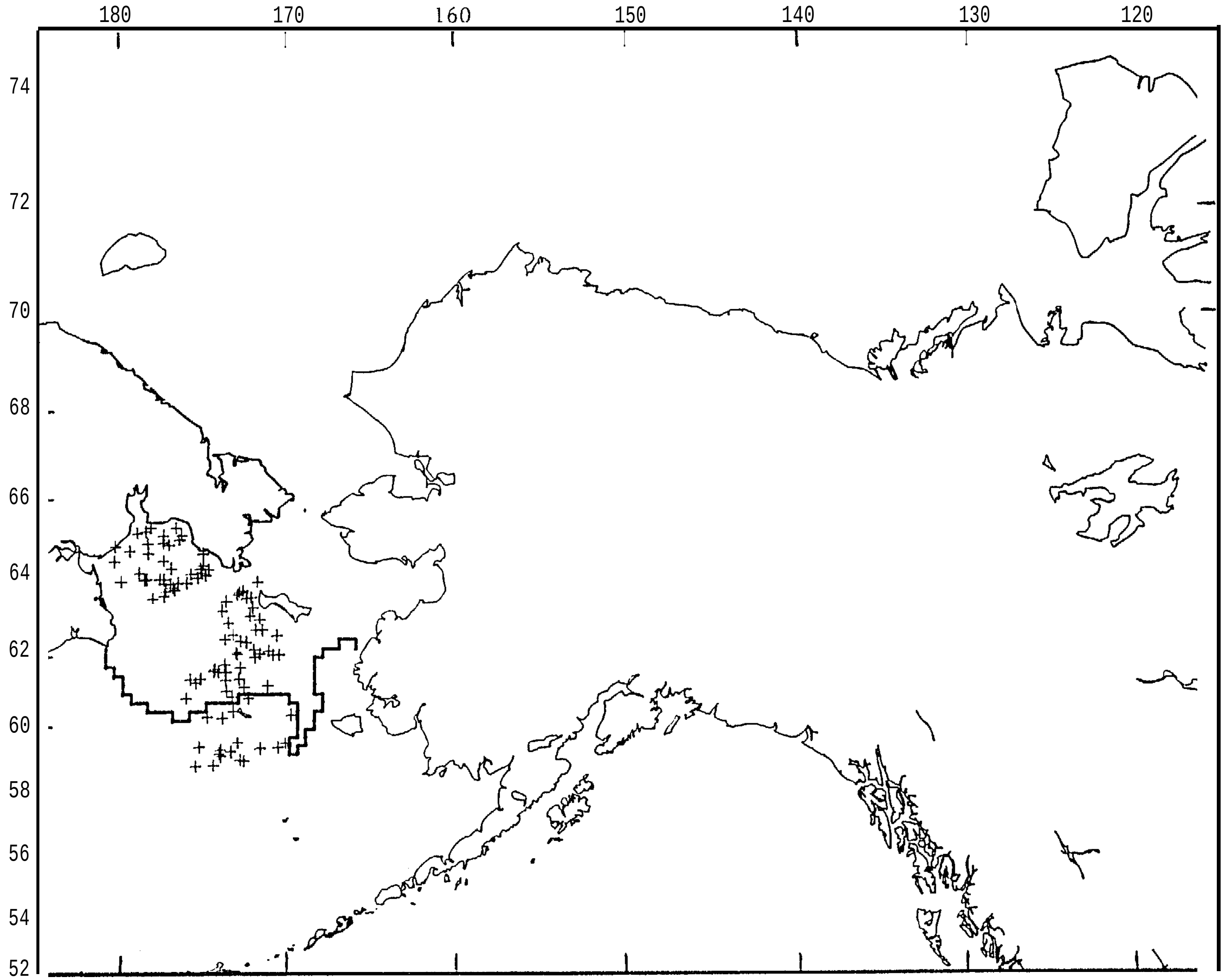



Figure 2-6c. Simulated distribution of 100 bowhead whale points on March 1. Heavy line is limit of 9/10 ice cover.

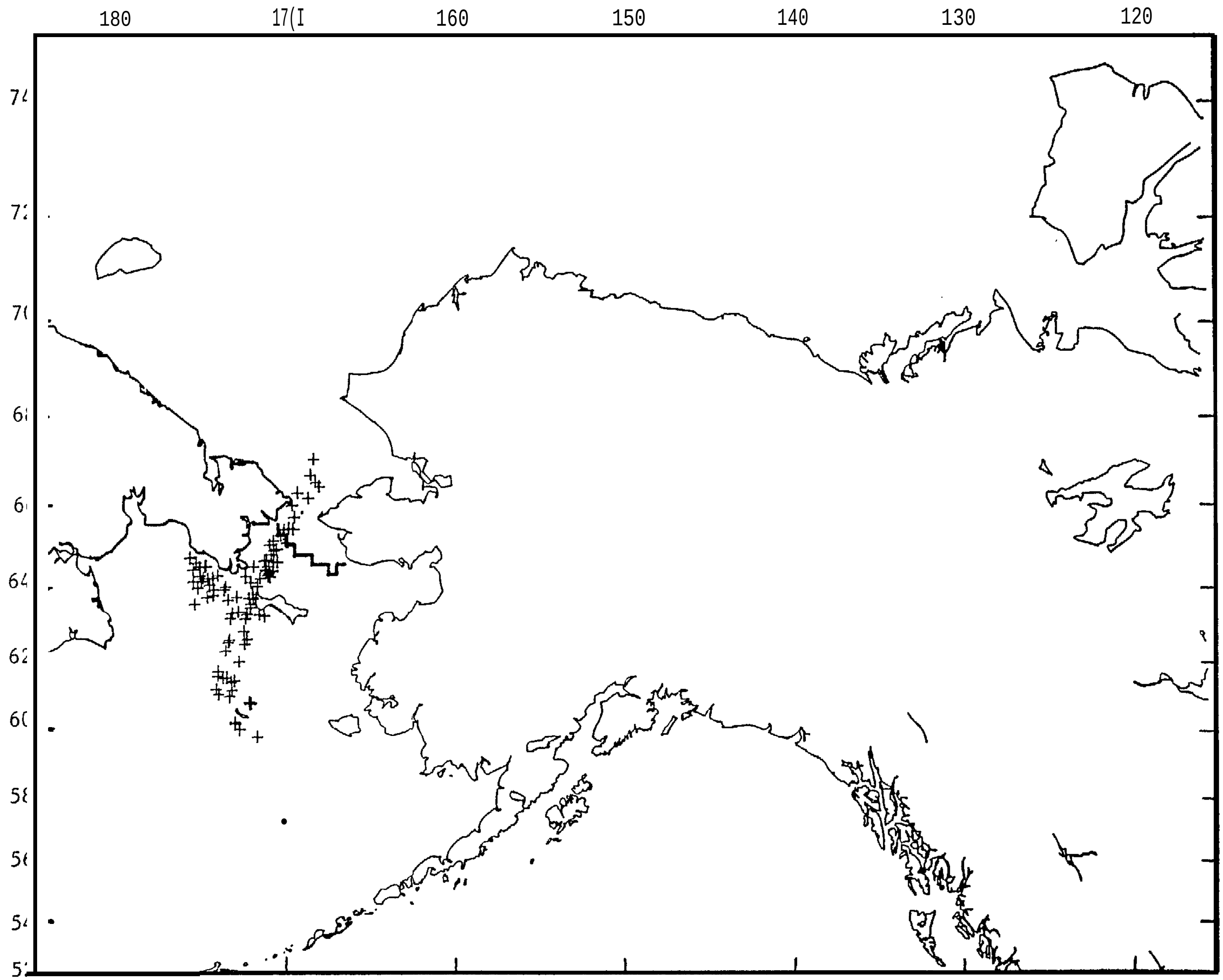



Figure 2-6d. Simulated distribution of 100 bowhead whale points on April 1. Heavy line is limit of 9/10 ice cover.

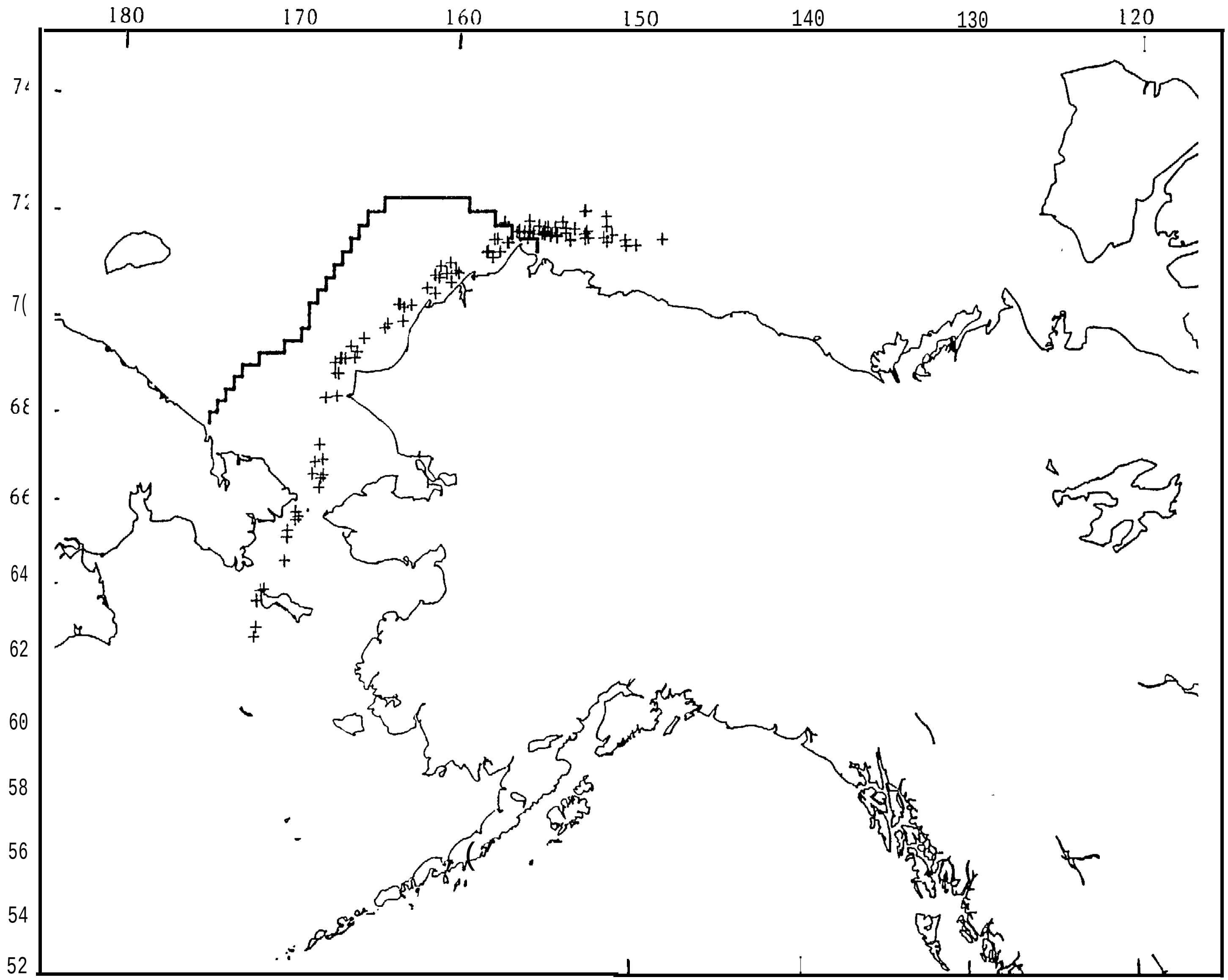



Figure 2-6e. Simulated distribution of 100 bowhead whale points on May 1. Heavy line is limit of 9/10 ice cover.

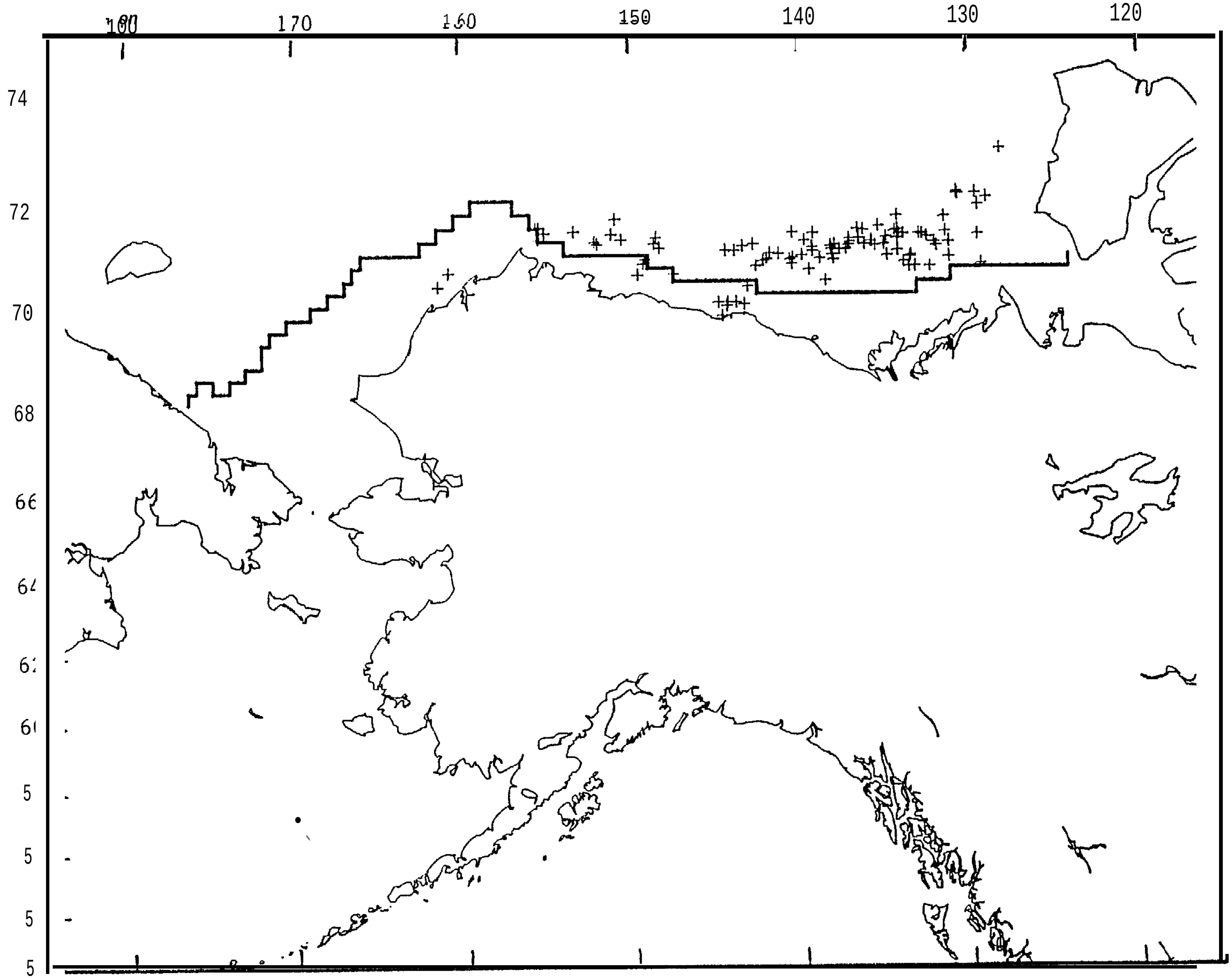



Figure 2-6f. Simulated distribution of 100 bowhead whale points on June 1. Heavy line is limit of 9/10 ice cover.

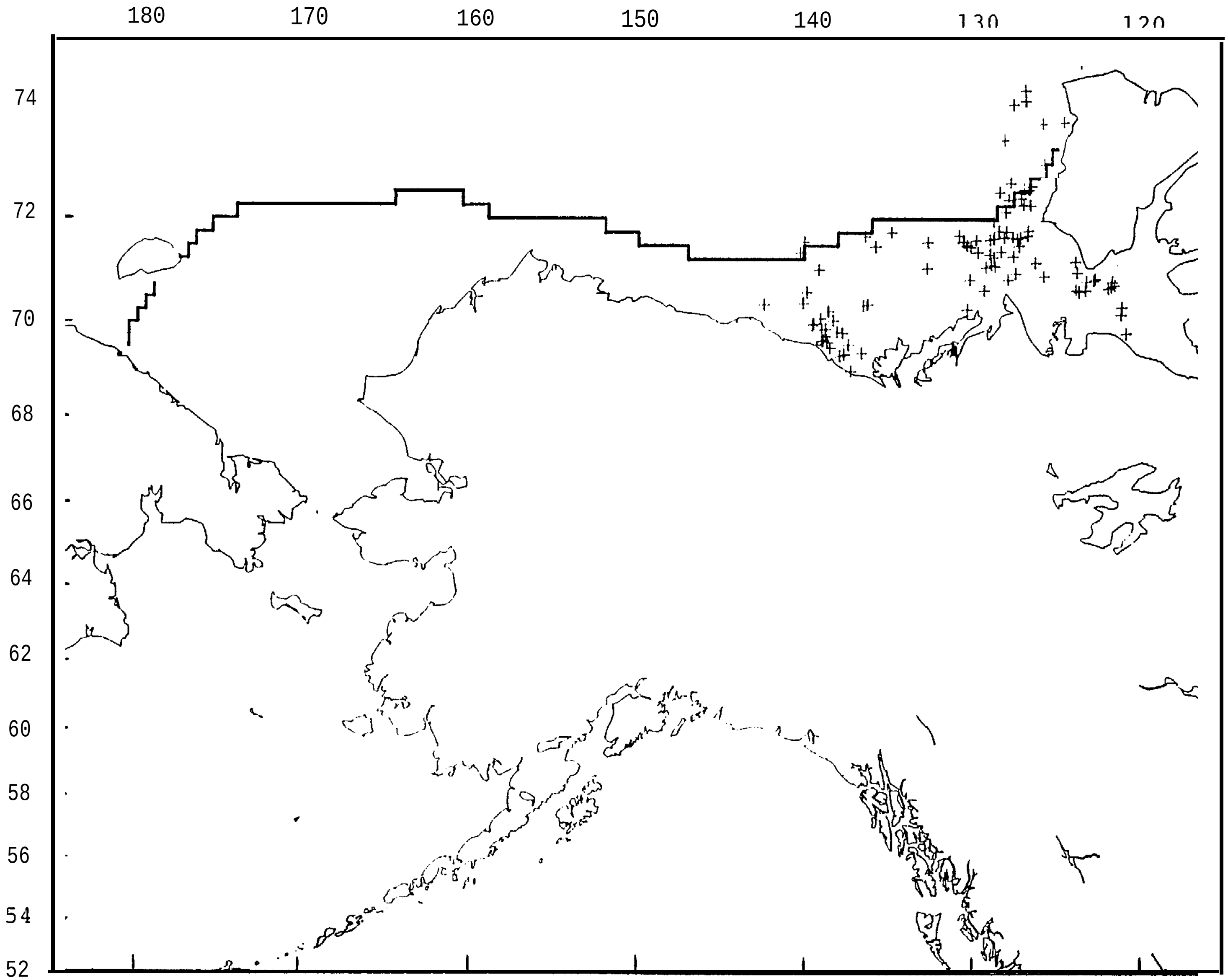



Figure 2-6g. Simulated distribution of 100 bowhead whale points on July 1. Heavy line is limit of 9/10 ice cover.

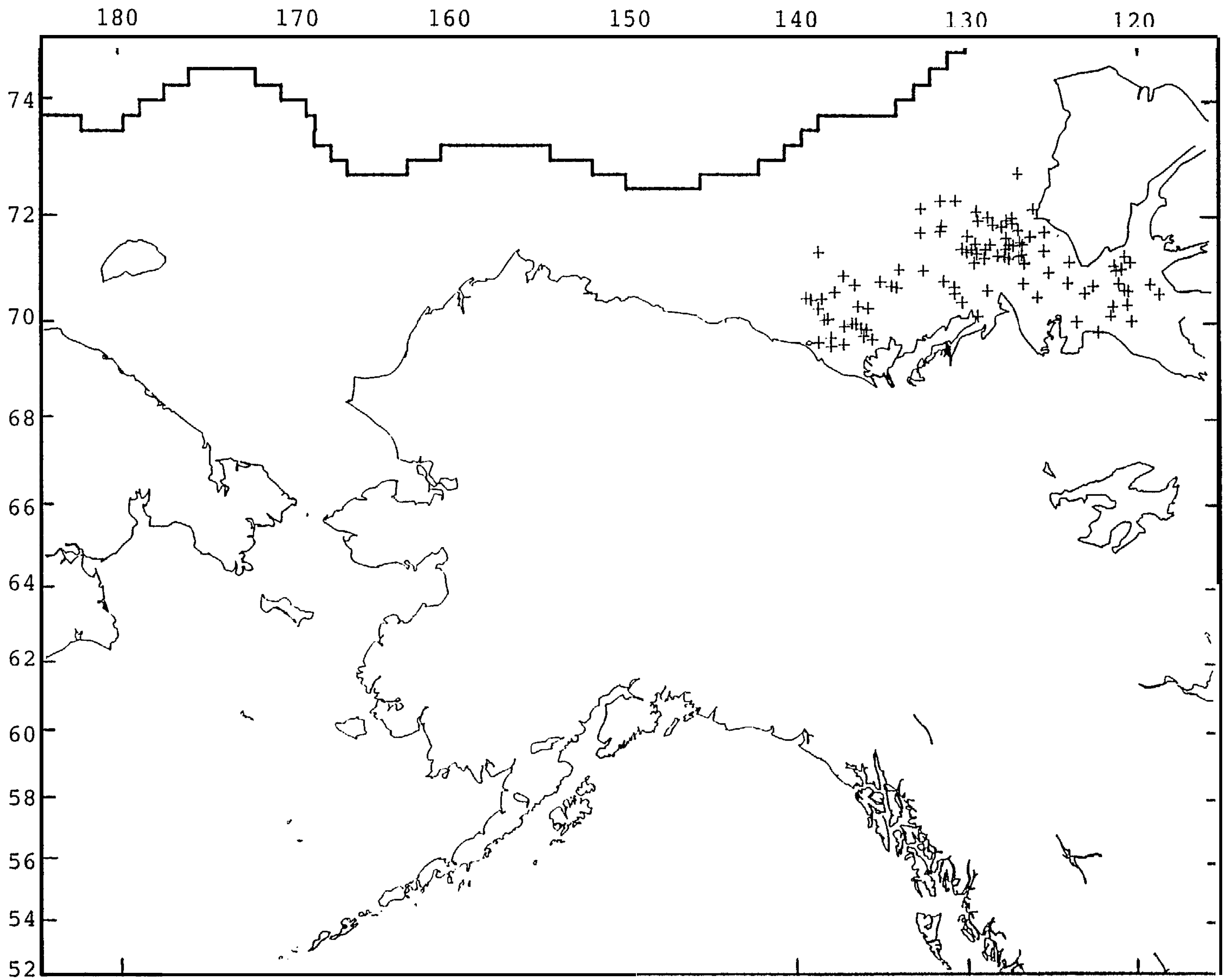



Figure 2-6h. Simulated distribution of 100 bowhead whale points on August 1. Heavy line is limit of 9/10 ice cover.

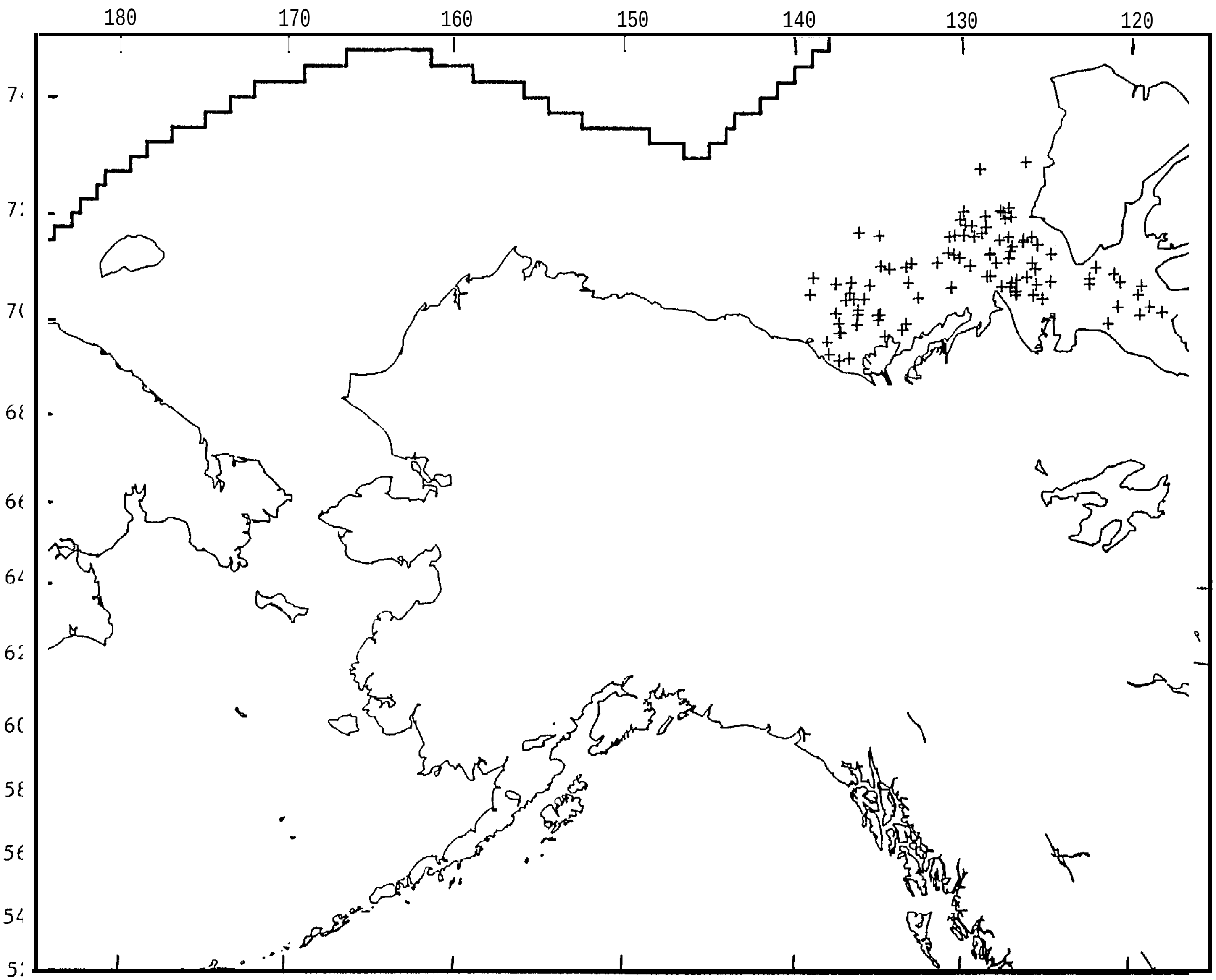



Figure 2-6i. Simulated distribution of 100 bowhead whale points on September 1. Heavy line is limit of 9/10 ice cover.

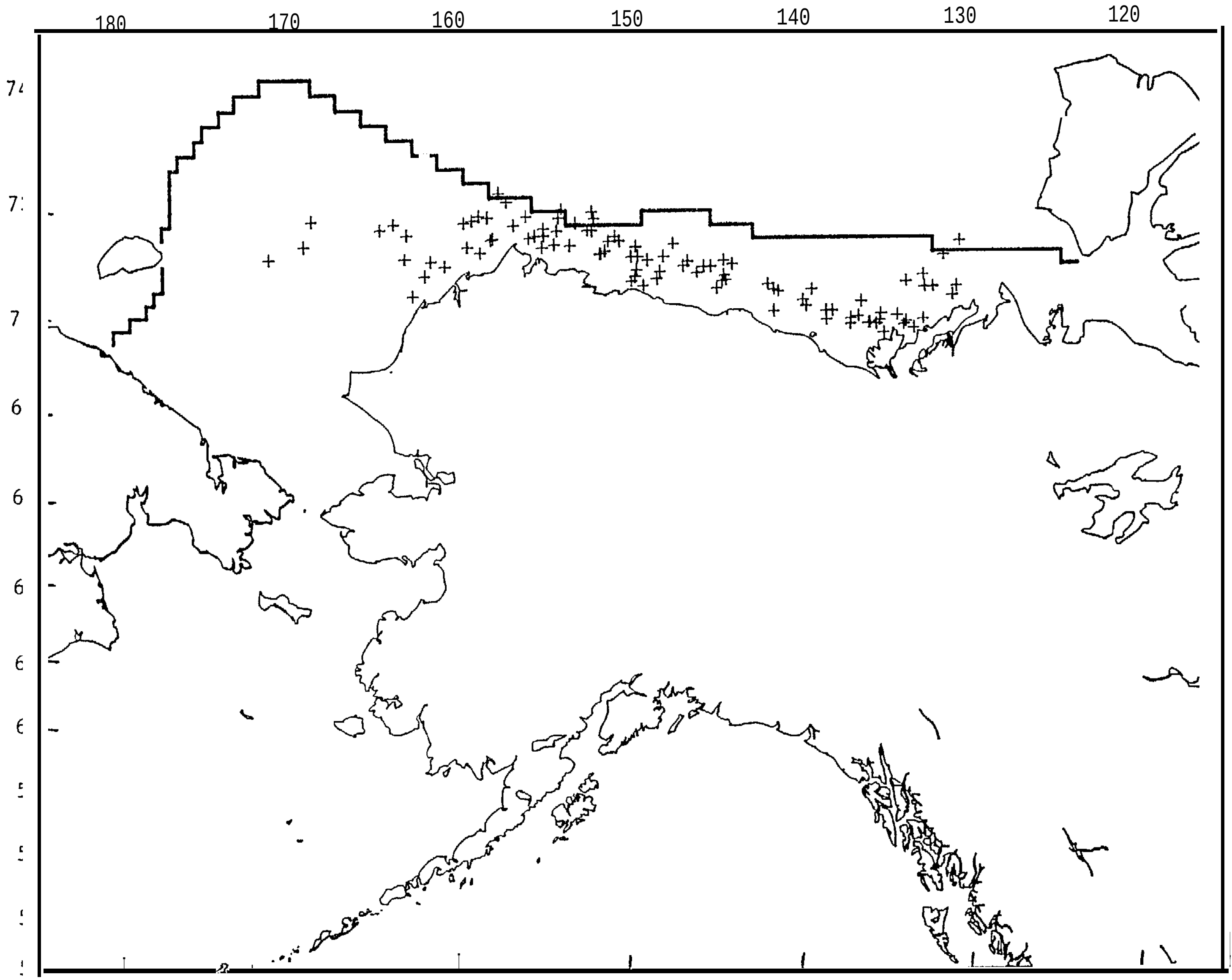



Figure 2-6j. Simulated distribution of 100 bowhead whale points on October 1. Heavy line is limit of 9/10 ice cover.

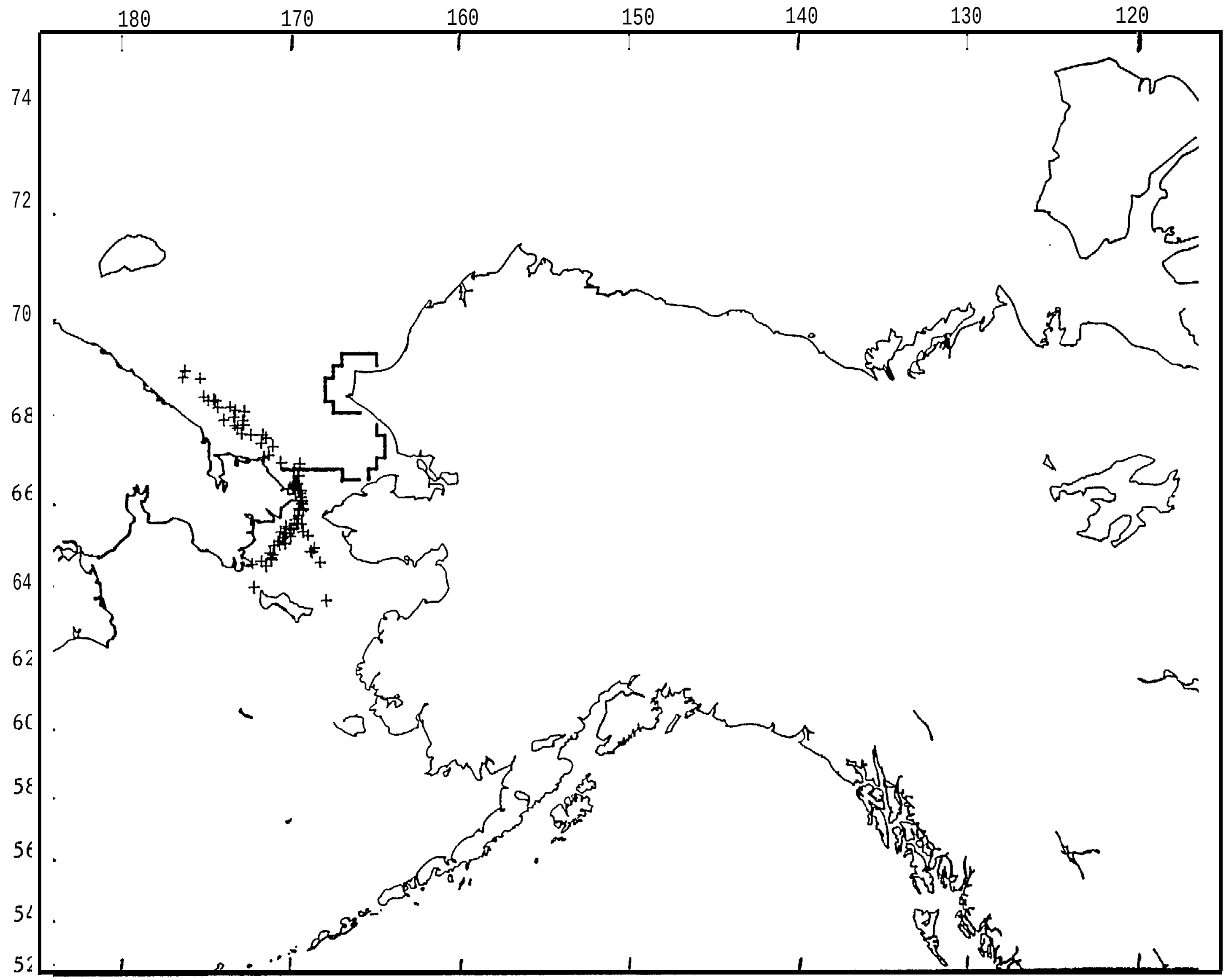



Figure 2-6k. Simulated distribution of 100 bowhead whale points on November 1. Heavy line is limit of 9/10 ice cover.

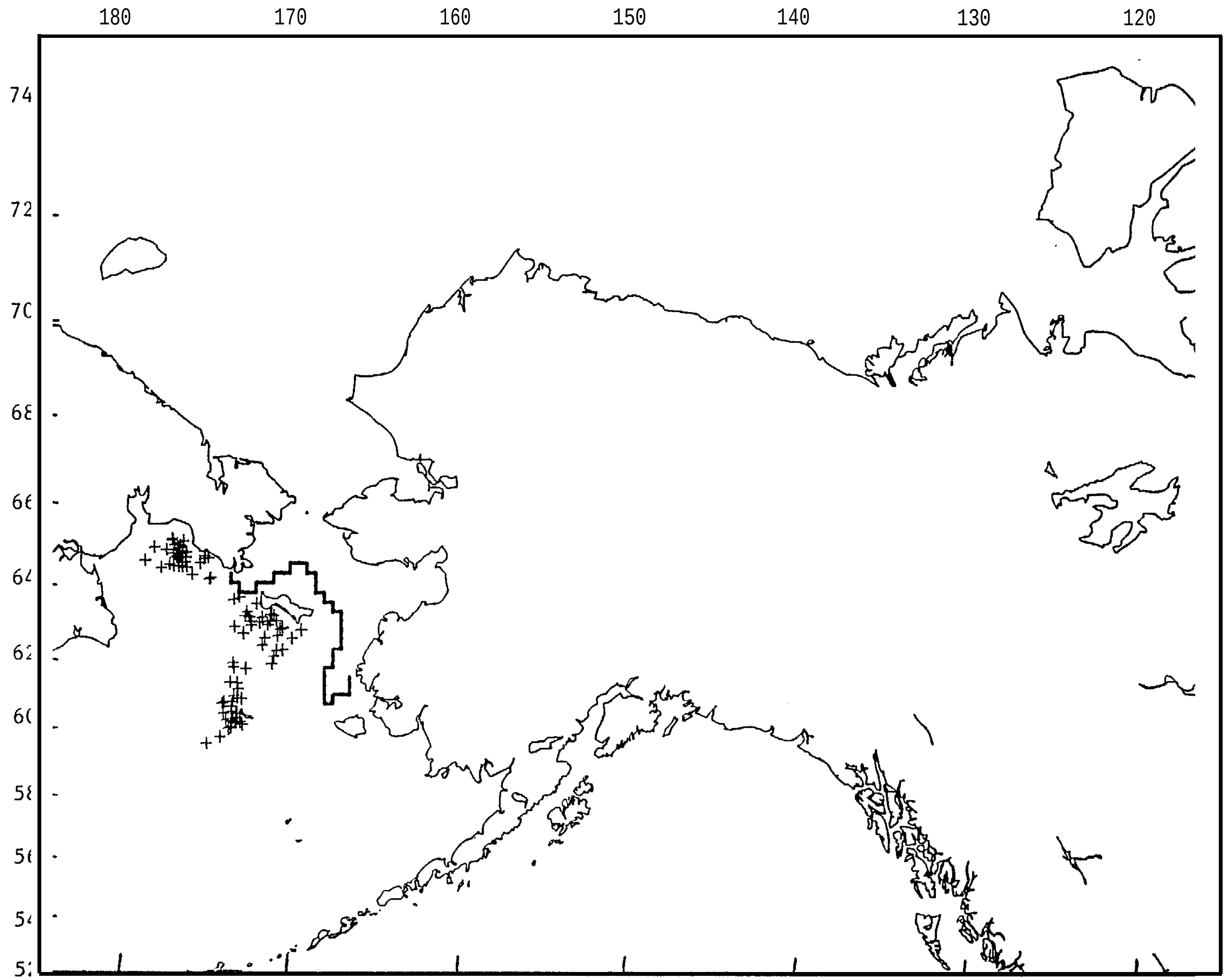



Figure 2-61. Simulated distribution of 100 bowhead whale points on December 1. Heavy line is limit of 9/10 ice cover.

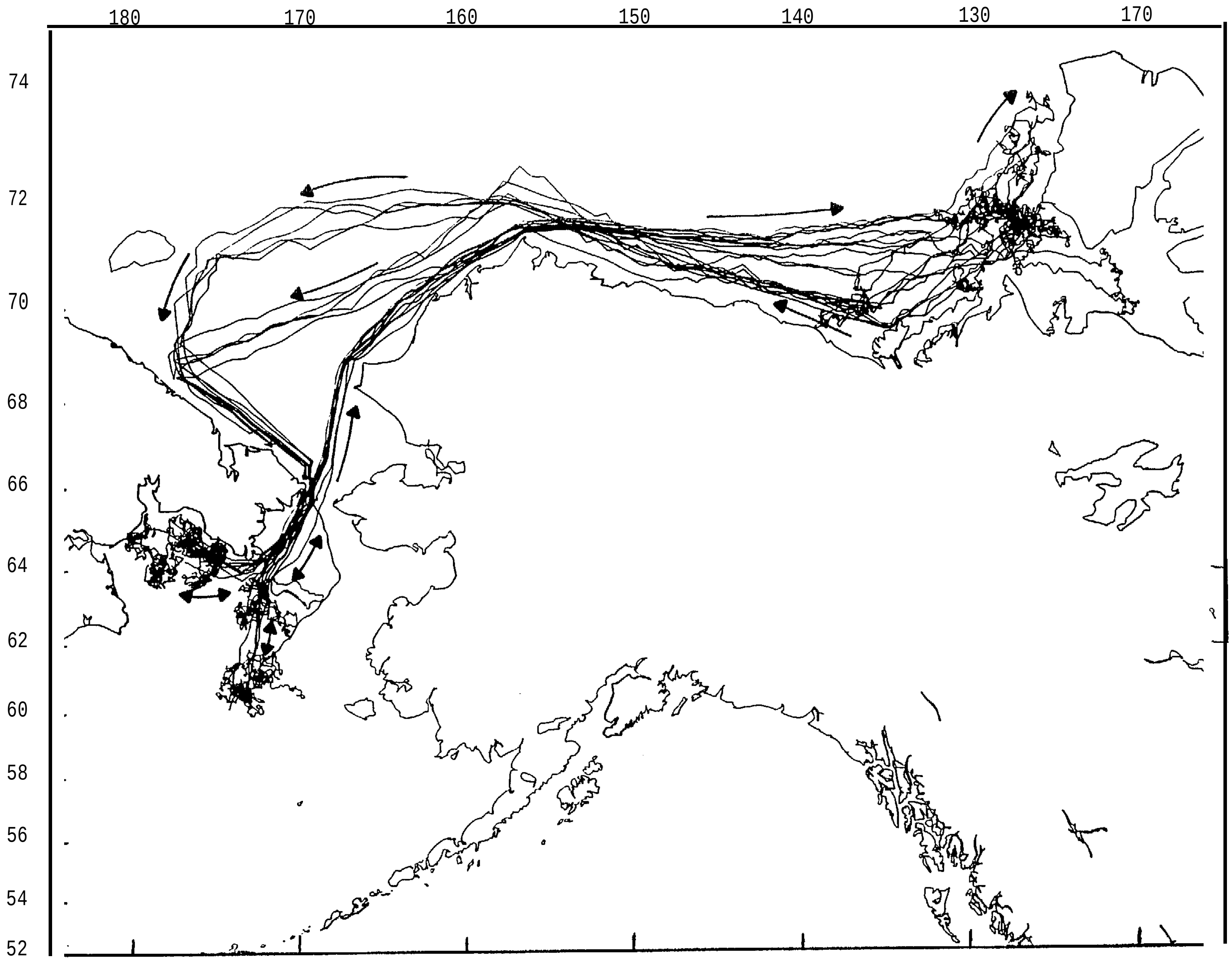



Figure 2-7. Routes followed by 10 bowhead whale points during a simulated annual migration.

$$P_{obs} = \frac{S_1 + S_2 + 2B}{2N}$$

where

$P_{obs}$ = probability of a single observer sighting a whale
$S_1, S_2$ = number of sightings made by the two observers independently
B · number of sightings made by both observers
N · the estimated number of groups of whales, calculated using $S_1, S_2$, and B

Variances are calculated for both $P_{obs}$ and N, using a procedure outlined in Davis et al (1982), and these are factored into the final variance figures. The value of $P_{obs}$ is on the order of 0.70 for the studies conducted in the Canadian Beaufort, and the standard deviation on the order of 0.18.

A similar correction factor is calculated for submerged whales. The factor used by Davis et al (1982, pp. 54) was modified to correct for the extreme skew and modality in the distribution of surfacing intervals; we will not report it here. However, in principal it consists of the sum of the probability that the whale is at the surface at the time of an encounter and the probability that it will be at the surface while the aircraft is within visual range of the whale,

$$P_{surf} = \frac{S + T}{S + U}$$

where

$P_{surf}$ = the probability that the whale will be at the surface
S · the time spent by the whale at the surface
T · the time the aircraft is within visible range of an object at the surface
u " the time spent by the whale under the surface

The correction for submerged whales was $P_{surf} = 0.261 \pm 0.025$ during the 1981 study season in the Canadian Beaufort. The overall density estimate is thus

$$N_{corr} = \frac{N_{uncorr}}{P_{obs} * P_{surf}}$$

where

$N_{corr}$ = the number of sightings corrected for missed and submerged whales

$N_{uncorr}$ = the number of sightings made during the survey

The scaling factor for the uncorrected number of whales was approximately 0.18 for the 1981 survey season. Differences between individual surveys were taken into account during the actual calculations, so that the factor $P_{obs}*P_{surf}$ varied somewhat. This factor accounts for as much as an eight-fold difference between observed density and corrected density.

Most studies did not report corrected density estimates. The effort made during the summer studies in the Canadian Beaufort has been heavy in a relatively small area; other studies have encompassed much larger areas and longer periods, where estimates of time spent at the surface by the whales could not be made practicably.

To use the observed whale densities for calibration, the mean and standard deviation of the observations in each surveyed region for each season were calculated. When only one seasonal survey had been performed in a region, the one observation was assumed to be the mean. A standard deviation was then estimated as the average coefficient of variation for all surveyed regions during that season times the mean. The average coefficient of variation is the averaged ratios of standard deviation to the means of all observations for which a standard deviation was calculable in a given season:

$$CV = 1/n \sum_{i=1}^{n} s_i/x_i$$

where

CV = average coefficient of variation

n = number of areas in which more than one density estimate was available.

$s_i$ = standard deviation of density estimates in area i

Xi = mean of density estimates in area i

For August data, CV was calculated to be 1.1; this value was used to estimate standard deviations in July and August. Standard deviations in September were estimated from a CV of 1.2 calculated from September/October data.

A simulated density, Ds, is computed by summing the number of whales in each polygon (survey block) at the end of each simulation day for each day of the observation period, and dividing by the total number of "observation days" multiplied by the area of the survey block:

$$D_s = (NW \cdot WP)/(ND \cdot A)$$

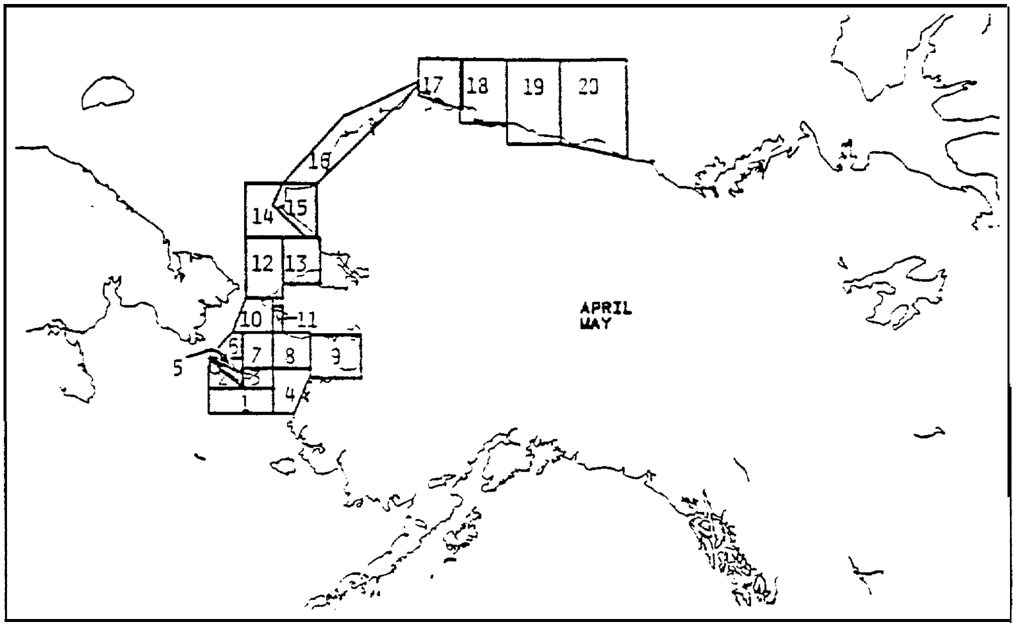
where

Ds = simulated whale density (whale/km*)
NW = total number of whale points in survey area during all days of survey
WP = number of whales represented by each whale point
ND = number of days of survey
A = surveyed area ($km^2$)

After comparison of observed and simulated densities, the simulated migration was adjusted to attempt to bring simulated densities within one standard deviation of the mean observed density in each region. Adjustments were made to the percent of the population following various routes and going to the different hold points. Opening and closing dates of the branch points were also adjusted. The route itself was not altered.

Figures 2-8a through e present the results of the calibration for those times end areas for which density estimates are available. Figure 2-8a, which gives the dens i ty comparisons for April/May, shows differences greater than one standard deviation between observed and simulated densities in Areas 14, 19 and 20. According to the hypothesized migration route, all whales traveling between Areas 12 and 16 must pass through Areas 14 and/or 15, Although the simulation model is generating acceptable densities in Areas 12 and 16, those in Area 14 are high by almost 3 standard deviations. Combining the whale densities in Areas 14 and 15 still results in differences of almost 3 standard deviations between observed and simulated densities. This seems to indicate errors in observed density estimates in these areas, since the whales must pass from Areas 12 to 16 via this route. Other discrepancies between observed and simulated densities occur in Areas 19 and 20, possibly indicating that simulated whales are arriving in the western Beaufort Sea too soon. However, simulated and observed histograms of first time-of-passage at Point Barrow (Figure 2-9) are in fair agreement. The discrepancies between observed and simulated densities in Areas 19 and 20 may therefore be due to the consistently poor conditions under which the surveys are made, and the difficulty of sighting whales traveling through heavy ice cover. If the observations are correct, then the model tends to overestimate whale densities in this area in early spring, and will therefore overestimate interactions with potential oil spills.

Since the mean and standard deviation of observed densities

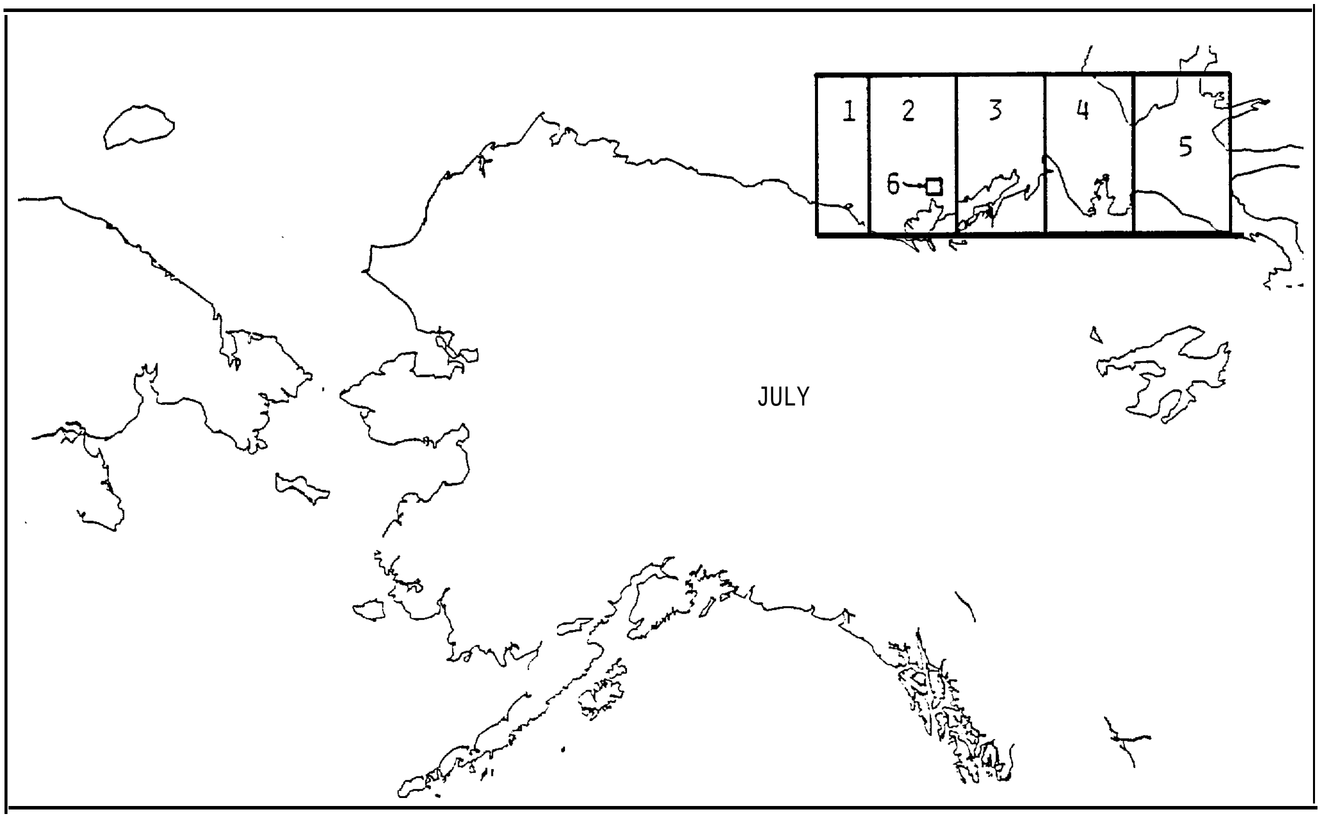



| Survey Area | Number of Observations | Observed Density * Mean | Observed Density * Std. Dev. | Simulated Mean Density * | Number of std. devs. from the observed mean |
|---|---|---|---|---|---|
| 1 | 3 | 0.0 | 0.0 | .00006 | + |
| 2 | 3 | 0.0 | 0.0 | .00352 | + |
| 3 | 3 | .00029 | .00050 | 0.0 | -0.6 |
| 4 | 3 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5 | 3 | 0.0 | 0.0 | .00125 | + |
| 6 | 4 | .05260 | .10525 | .00660 | -0.4 |
| 7 | 4 | .00276 | .00414 | 0.0 | -0.7 |
| 8 | 4 | .00022 | .00044 | 0.0 | -0.5 |
| 9 | 3 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | 4 | .00203 | .00163 | .00148 | -0.3 |
| 11 | 4 | .00051 | .00102 | 0.0 | -0.5 |
| 12 | 4 | .05335 | .09400 | .01653 | -0.4 |
| 13 | 2 | 0.0 | 0.0 | 0.0 | 0.0 |
| 14 | 4 | .00357 | .00420 | .01565 | +2.9 |
| 15 | 4 | .00686 | 000797 | .00133 | -0.7 |
| 16 | 4 | .00918 | .00635 | .01012 | +0.1 |
| 17 | 4 | .02374 | .00947 | .02984 | +0.6 |
| 18 | 4 | .01580 | .00566 | .01927 | +0.6 |
| 19 | 4 | .00409 | .00573 | .01106 | +1.2 |
| 20 | 4 | .00260 | .00326 | .00817 | +1.7 |

* Density in whales/$km^2$

\+ A + with no following number indicates the simulated density is higher than observed, but the number of standard deviations-from the mean could not be calculated.

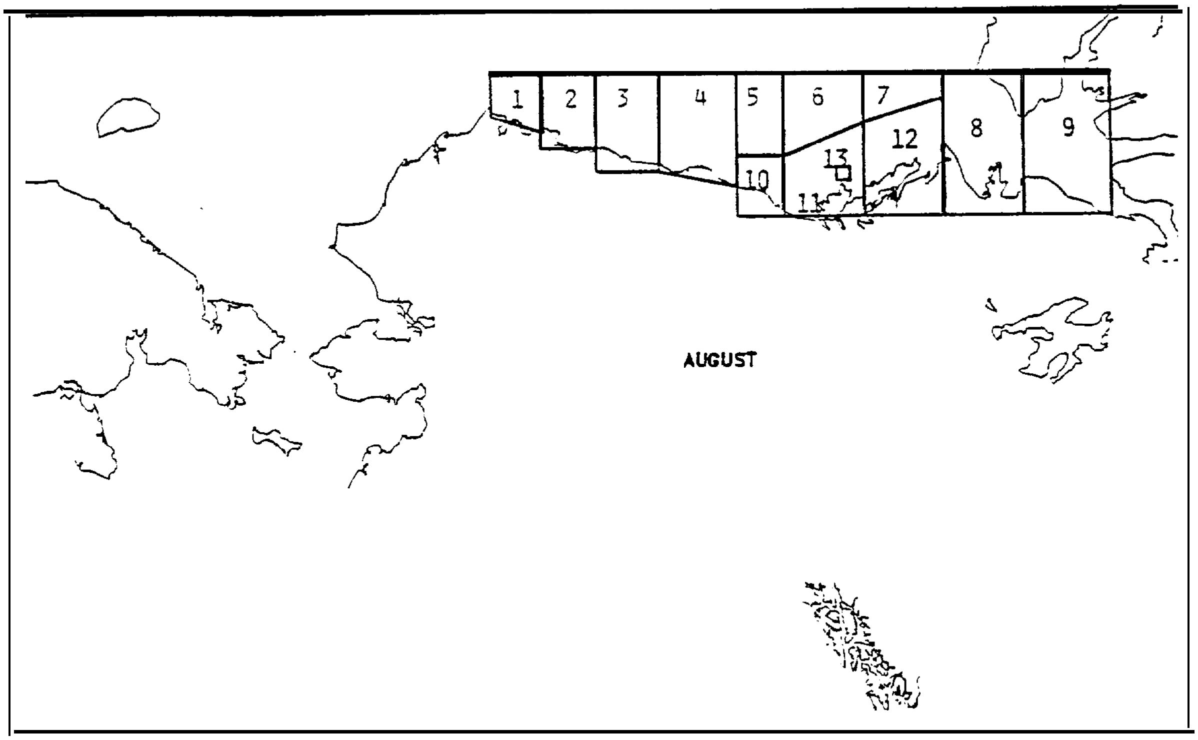
Figure 2-8a. Comparison of observed and simulated bowhead whale densities for April/May.




| Survey Area | Number of Observations | Observed Density * Mean | Observed Density * Std. Dev. | Simulated Mean Density * | Number of std. devs. from the observed mean |
|---|---|---|---|---|---|
| 1 | 1 | .00923** | .01015 | .01477 | +0.5 |
| 2 | 1 | .00108** | .00119 | .01077 | +8.1 |
| 3 | 1 | .00081** | .00089 | .02757 | +30.1 |
| 4 | 1 | .01590** | .01749 | .01987 | +0.2 |
| 5 | 1 | .00638** | .00702 | .01335 | +1.0 |
| 6 | 1 | .01970 | .02167 | 0.0 | -0.9 |

* Density in whales/$km^2$
** Estimate corrected for submerged and/or missed whales

Figure 2-8b. Comparison of observed and simulated bowhead whale densities for July.



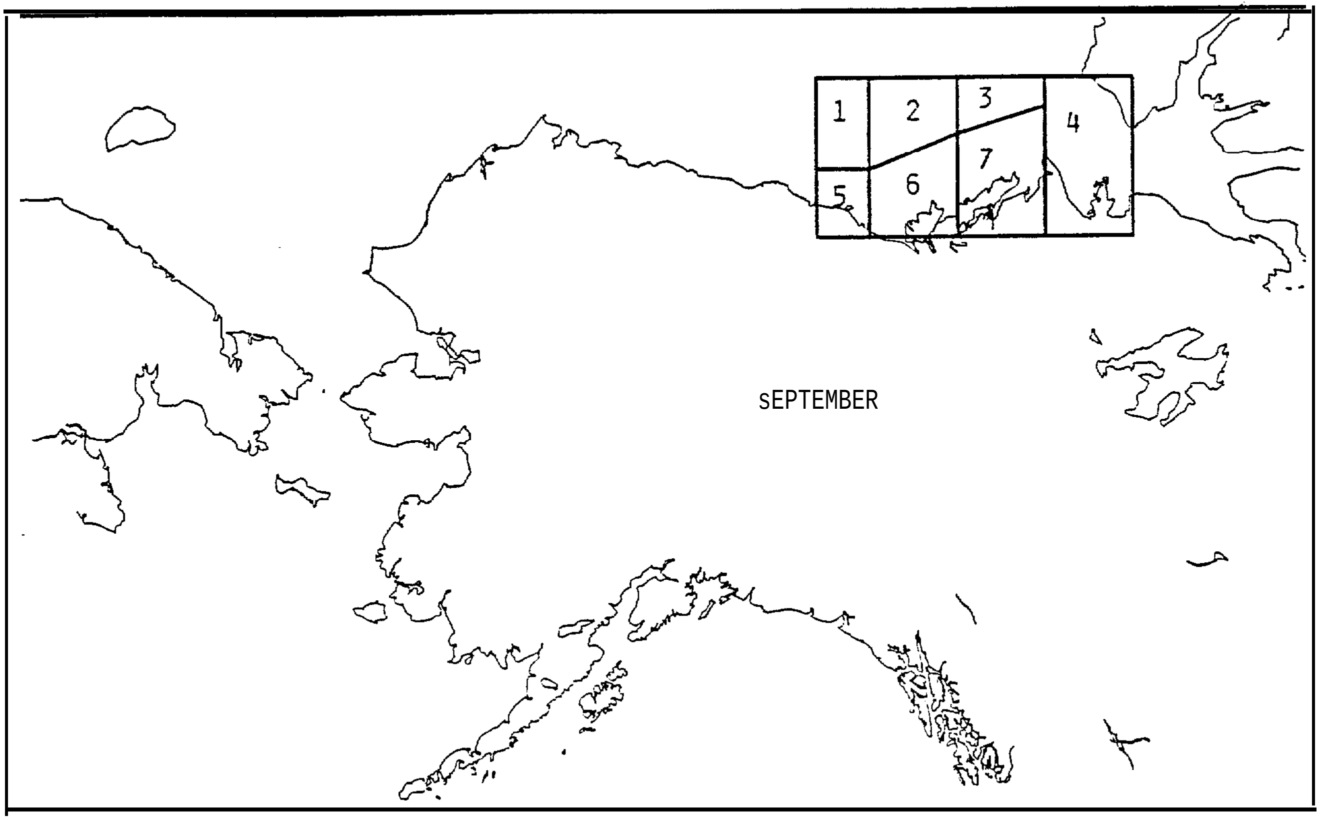

| Survey Area | Number of Observations | Observed Density * Mean | Observed Density * Std. Dev. | Simulated Mean Density * | Number of std. devs. from the observed mean |
|---|---|---|---|---|---|
| 1 | 2 | .00015 | .00021 | 0.0 | -0.7 |
| 2 | 2 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 | 2 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4 | 2 | .00205 | .00205 | 0.0 | -1.0 |
| 5 | 1 | .01960** | .02156 | .00296 | -0.8 |
| 6 | 1 | .05545** | .06100 | .02071 | -0.6 |
| 7 | 1 | .01785** | .01964 | .02456 | +0.3 |
| 8 | 1 | .00512** | .00563 | .02163 | +2.9 |
| 9 | 1 | 0.0 | 0.0 | .01455 | + |
| 10 | 1 | .02640 | .02904 | .00517 | -0.7 |
| 11 | 1 | .00093 | .00102 | .02485 | +23.5 |
| 12 | 2 | .01476 | .01872 | .01571 | +0.1 |
| 13 | 1 | .01970 | .02167 | .01889 | 0.0 |

* Density in whales/$km^2$

** Estimate corrected for submerged and/or missed whales

\+ A + with no following number indicates the simulated density is higher than observed, but the number of standard deviations from the mean could not be calculated.

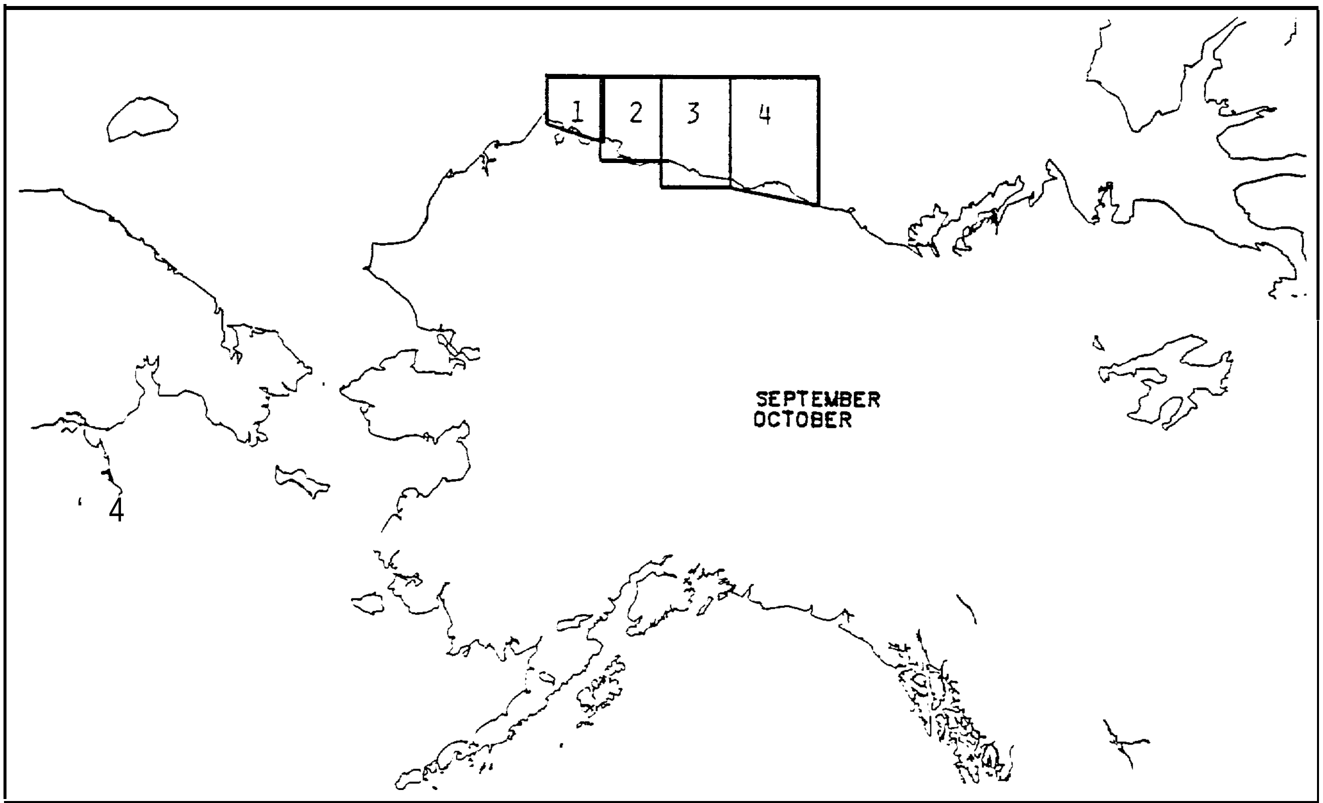
Figure 2-8c. Comparison of observed and simulated bowhead whale densities for August. Areas 10, 11 and 12 are subsets of Areas 5, 6 and 7, respectively.




| Survey Area | Number of Observations | Observed Density * Mean | Observed Density * Std. Dev. | Simulated Mean Density * | Number of std. devs. from the observed mean |
|---|---|---|---|---|---|
| 1 | 1 | .01700** | .02040 | .01036 | -0.3 |
| 2 | 1 | .01520** | .01824 | .02022 | +0.3 |
| 3 | 1 | .03150** | .03780 | .02343 | -0.2 |
| 4 | 1 | .01580** | .01896 | .01176 | -0.2 |
| 5 | 1 | .01250 | .02580 | .02059 | 0.0 |
| 6 | 1 | .00055 | .00066 | .02648 | +39.3 |
| 7 | 2 | .00624 | .00815 | .01975 | +1.7 |

* Density in whales/km$^2$
** Estimate corrected for submerged and/or missed whales

Figure 2-8d. Comparison of observed and simulated bowhead whale densities for September. Areas 5, 6 and 7 are subsets of Areas 1, 2 and 3, respectively.




| Survey Area | Number of Observations | Observed Density * Mean | Observed Density * Std. Dev. | Simulated Mean Density * | Number of std. devs. from the observed mean |
|---|---|---|---|---|---|
| 1 | 5 | .00120 | .00097 | .00641 | +5.4 |
| 2 | 5 | .00403 | .00689 | .00623 | +0.3 |
| 3 | 5 | .00239 | .00287 | .00665 | +1.5 |
| 4 | 5 | .00350 | .00390 | .00705 | +0.9 |

*Density in whales/$km^2$

Figure 2-8e. Comparison of observed and simulated bowhead whale densities for September/October.

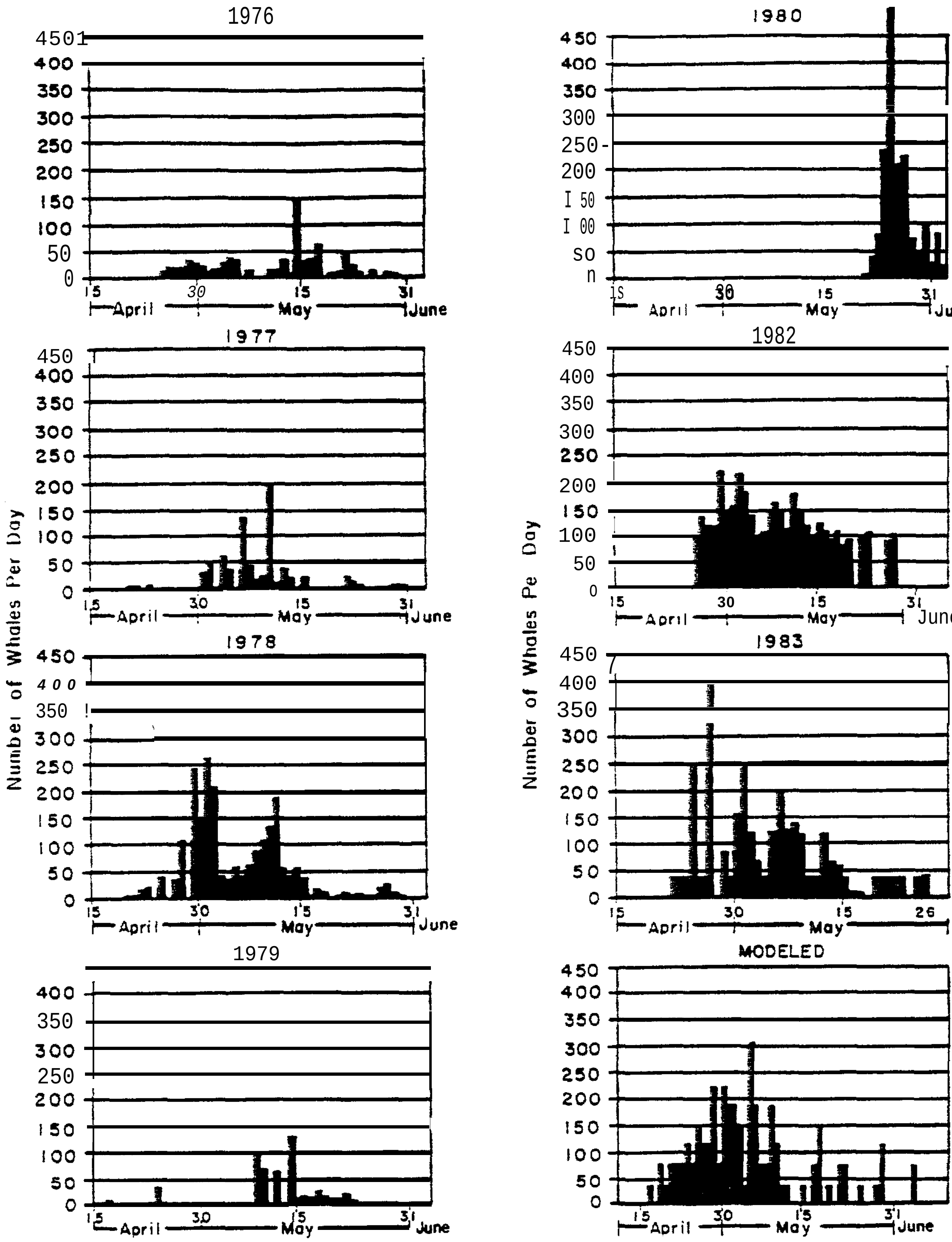



Figure 2-9. Observed and simulated distributions of bowhead whales passing Pt. Barrow, Alaska. Simulation assumes a population of 3800 whales. Observed data for 1976-1978 after Braham et al (1984); for 1979 after Braham et al (1980a); for 1980 after Johnson et al (1981); for 1982 after "Dronenburg et al (1983); and for 1983 after Dronenburg et al (1984).

in Areas 1, 2, and 5 are zero, the number of standard deviations by which the simulated value differs from the value observed could not be calculated. The simulation allows whales overwintering near St. Matthew Island to pass through Areas 1 and 2 on their spring migration, and a few stray into Area 5 as well. The lack of sightings in these areas is either a result of the difficult ice and weather renditions under which the surveys are taken, or else indicates that whales from the south travel further to the west or east than in the model. Since simulated densities in these areas are small, it was decided not to arbitrarily adjust the migration route at this time.

The density comparisons for July (Figure 2-8b) are based on only one year of data and thus are not necessarily indicative of the mean towhead whale distribution. In Areas 2 and 3 the simulated densities are considerably greater than those observed. Observed densities in these areas are as much as a factor of 19 lower than observed densities in the surrounding areas, which agrees with various reports of bowhead whales not moving into the areas off the Mackenzie Delta and Tuktoyaktuk Peninsula until August (Fraker et al, 1978). However, increasing the numbers of simulated bowhead whales in areas east and west of this region to reduce the simulated densities in Areas 2 and 3 would result in unacceptably high densities in Areas 1, 4 and 5. An integration of the observed densities over the surveyed areas accounts for only 1430 animals. Obviously the surveys are underestimating the number of animals in each area, or the bowhead whales have additional summer feeding areas which have not been surveyed to determine densities, or the population size has been overestimated. Several recent studies have indicated that the whales are often very patchy in distribution (Richardson, 1982; Cubbage et al, 1984). If the population is distributed in large patches, and these patches are missed due to low survey effort, the population in those areas will also be underestimated. The entire modeled population of 3800 whales is in this area for the months of July and August (Figures 2-6g,h), so it is clear that densities in some areas will be overestimated, given the available data.

The August density comparisons (Figure 2-8c) show generally good agreement between observed and simulated densities in all areas except the Canadian Beaufort. In Areas 8 and 9 (Amundsen Gulf) observed densities are based on only one year's observations. Simulated densities are higher than observed, but anecdotal sightings report large numbers of animals present in the Gulf (Fraker and Bockstoce, 1980). The other problem area is the Mackenzie Delta (Area 11). Comparison of the observed densities shows the density in Area 11 (which is a subset of Area 6) is more than 50 times less than that in Area 6 as a whole, whereas Area 11, being closer to the coast, might be expected to have a greater density of whales (Fraker and Bockstoce, 1980). This apparent inconsistency in the observations makes good agreement between observed and simulated densities impossible.

The September density comparisons (Figure 2-8d) show simulated densities more than one standard deviation from the observed densities only in Areas 6 and 7. These areas, which are subsets of Areas 2 and 3, respectively, have observed densities which are much lower than observed in the larger areas, in which simulation and observation are in good agreement. Since the bowhead whales are generally expected to remain in relatively shallow waters' for feeding, the extremely low observed densities in Areas 6 and 7 seem anomalous. However, this problem is consistent between August (Area 11) and September (Area 6), indicating that the model may bring too many whales too close to shore in this area.

Figure 2-8e compares observed and simulated densities for the period September/October. Simulated densities are nearly constant in the four surveyed areas, while observed densities show a wide variability. In Areas 1 and 3 simulated densities are greater than one standard deviation from the mean observed value. However, in order for the bowhead whales to have time to cross the Chukchi Sea and reach the northern Bering Sea by November and December (Braham et al, 1984), it follows that most of the population will pass through Areas 1-4 during September and October. To reduce the number of animals passing through Area 1 to agree with observations would require holding the animals in the eastern Beaufort Sea until November, sending a greater number past Pt. Barrow in August, or moving the mean migratory path further offshore. None of these alternatives seems warranted in light of the current understanding of bowhead whale migration (Ljungblad et al, 1984). To the extent that whale densities in an area are overestimated by the simulation, whale-oilspill interaction potentials predicted by the model in these areas will be overestimated.

Limitations inherent in the collection of data may be responsible for some of the discrepancies we encountered. The Study effort and number of surveys taken varies among years. Survey methodologies vary between studies. Surveys reflect the effects of unusual years such as the late ice break-up in 1980 (Ljungblad et al, 1984). Individual whales do not always go to the same areas and their continual movement introduces the possibility of redundant observations. Extreme patchiness in the distribution, coupled with low survey coverage, can also result in underestimates. Observers do not see all the whales in the area surveyed, and corrections for missed or submerged whales are rarely reported. The combination of these factors results in the large degree of variability evident in the range of observed densities (Figures 2-8a - 2-8e). It is clear that the survey estimates underestimate total densities or large numbers of whales are present in areas not surveyed, since the hypothesized total population is seldom accounted for by an integration over the entire surveyed domain.

Figure 2-9 shows the observed and simulated number of bowhead whales passing Pt. Barrow each day in the spring. The observed data are derived from ice camp counts. The first whales generally reach Pt. Barrow in the third week of April. Subsequent whales pass in one to three peaks with the last whales passing in early June (Braham et al, 1984; Dronenburg et al, 1983).

Simulation results were compared with observations from 1978 (Table 2-2). This year was selected because it is considered to be one of the most complete census surveys taken at Pt. Barrow (Braham et al, 1984). Data taken during most other years is limited by the length of the survey and adverse ice and weather conditions. An F-test statistic was used to test for equal means and variances of the days of passing Pt. Barrow for the observed and simulated data sets. Comparison of the mean day of passing the ice camp for the observed and simulated data shows the hypothesis of equal means cannot be rejected at the 99% confidence level. However, the hypothesis of equal variance about the mean day of passing for the observed and simulated data can be rejected at the 95% confidence level, with the simulated data showing a higher variance. The model simulates greater temporal dispersion than was observed in 1978. The discrepancy is not necessarily significant, because the model accounts for every whale in the population, while the census counts miss whales due to whales passing beyond view of the ice camp, whales being submerged as they pass, and whales passing before or after the counts are taken. There is also considerable inter-annual variability, as shown in Figure 2-9. The year 1978 may not be typical.

Table 2-2. Statistical comparison of modeled and observed (1978) distributions of bowhead whales passing Pt. Barrow.

| Data Source | Mean Julian Day of Passage | Standard Deviation | Number of Observations |
|---|---|---|---|
| 1978 Observations | 126 | 7.4 | 2158 |
| Model Simulation | 125 | 11.0* | 100 |

*Standard deviations are significantly different from model at the 95% level (F = 2.21).

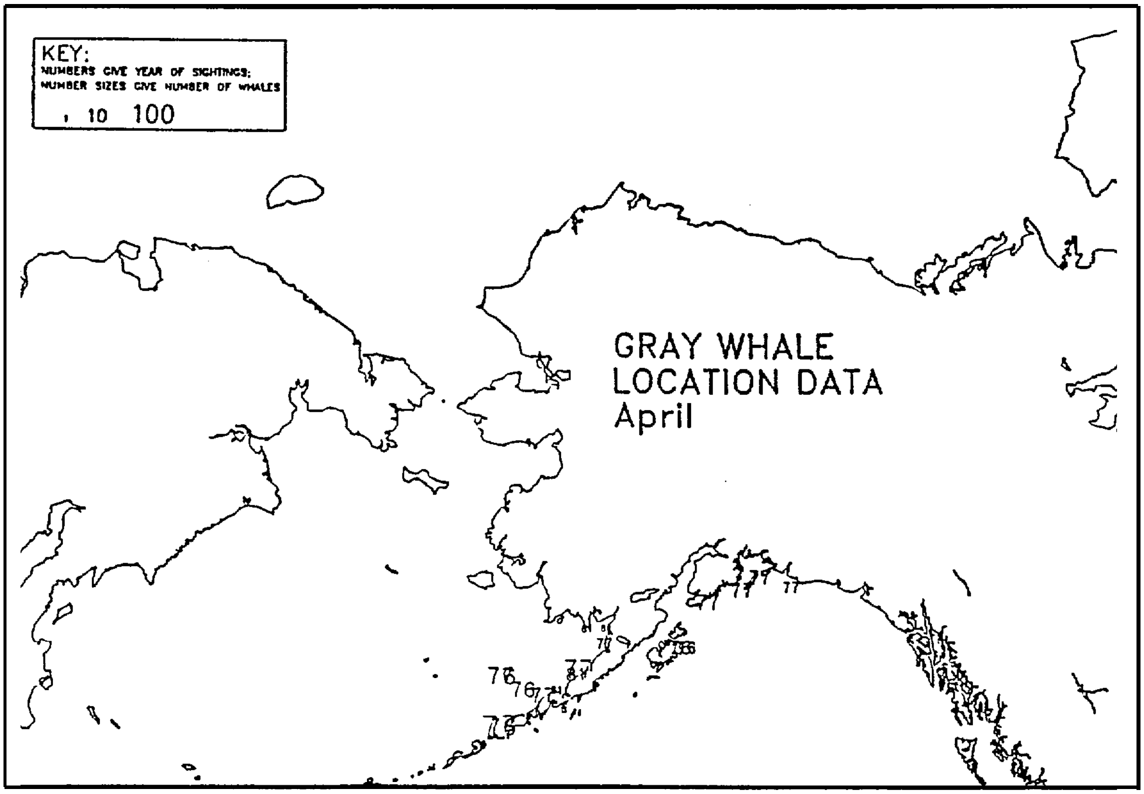
## 2.3 Gray Whale Model

Only a few differences exist between the formulations of the migration model for the gray whales and that for the bowhead whales. Because gray whales tend to travel very close to shore (Figures 2-10a through 2-10h), often within 1-3 km of the coast along much of their route in the southern Bering Sea (Braham, 1984; Rugh, 1984), a finer resolution grid was necessary to define land and ice (0.25 degree longitude, 0.125 degree latitude).

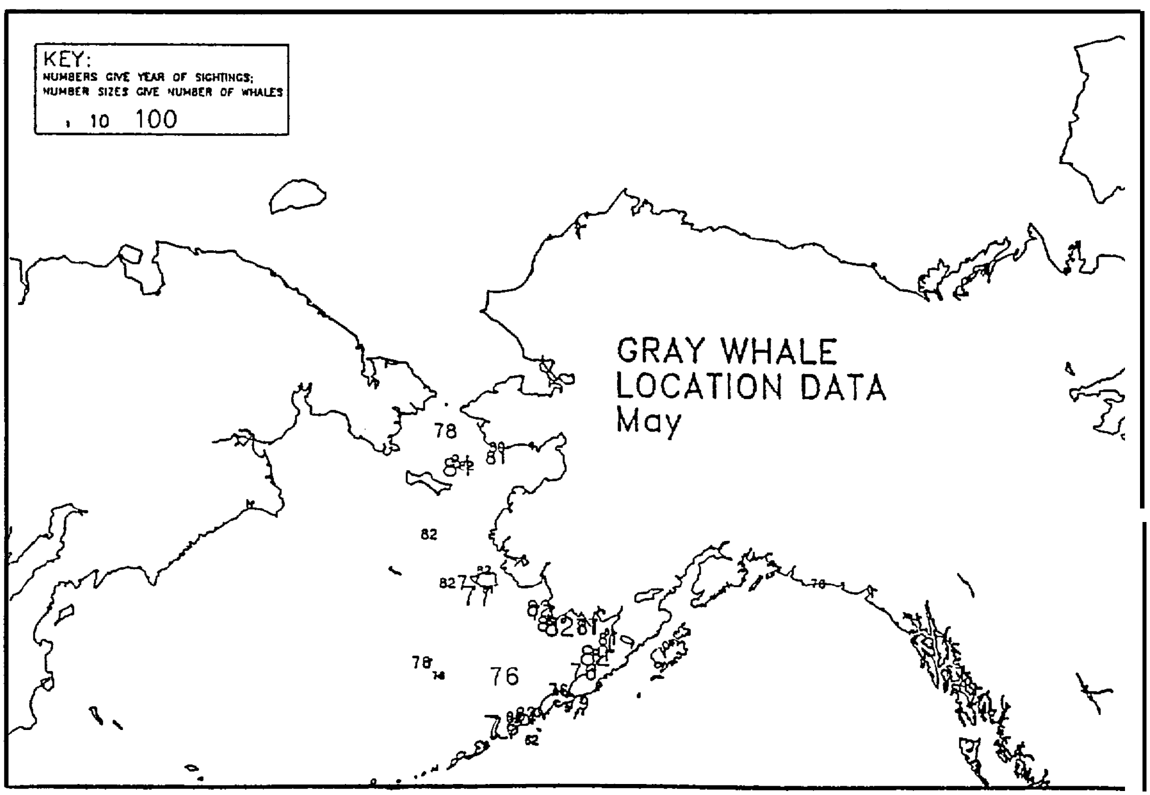
Although the annual migration of the gray whale stretches from Baja California to the Bering, Chukchi, or Beaufort Seas, this study is concerned only with their movements north of the Alaska Peninsula. Therefore simulations of gray whale migration begin and end at Unimak Pass. Simulations may be run for multiple years, but no locations are computed or stored for the periods between the whales' departure south through Unimak Pass in the fall and their arrival back at Unimak Pass in the spring. Initialization of the model therefore consists of specifying the temporal distribution of whales passing north through Unimak Pass.

Gray whales pass through Unimak Pass in the spring for roughly two months, beginning early in April (Hessing, 1983). During this time two or three peaks in the number of animals are generally observed (Braham, 1984). The model reproduces this type of behavior by allowing the user to specify the first day whales enter the Pass, the number, duration and timing of the peaks and the length of time required for the migration through Unimak Pass.

A major difference between bowhead and gray whales is the response of each to ice. Bowhead whales often live well inside the ice front. Gray whales have much less affinity for ice, generally preferring to remain outside the ice edge. Therefore, for simulation of the gray whale migration, the ice edge location (25%, 50%, and 75% probability of occurrence for heavy, medium, and light ice years, respectively) based on the ice atlas of LaBelle et al (1983) is used to define the limiting concentration of ice through which gray whales will not pass. The ice edge location varies at weekly intervals from April through September as shown in Figure 2-ha. During the rest of the year, the more slowly accreting ice edge varies at biweekly intervals (Figure 2-11b). The modeled movement of gray whales is constrained by ice during the spring and summer. Whales can move up to, but not through, the ice edge. Upon reaching the ice, simulated whales move in small random motions until the ice edge shifts. Starting in Cctober, the ice begins to advance southward. In general, gray whales have begun heading south by this time. Any whales which may be caught inside the accreting ice wver are given a speed 1.5 times their previously assigned speed until they regain open water. The factor of 1.5

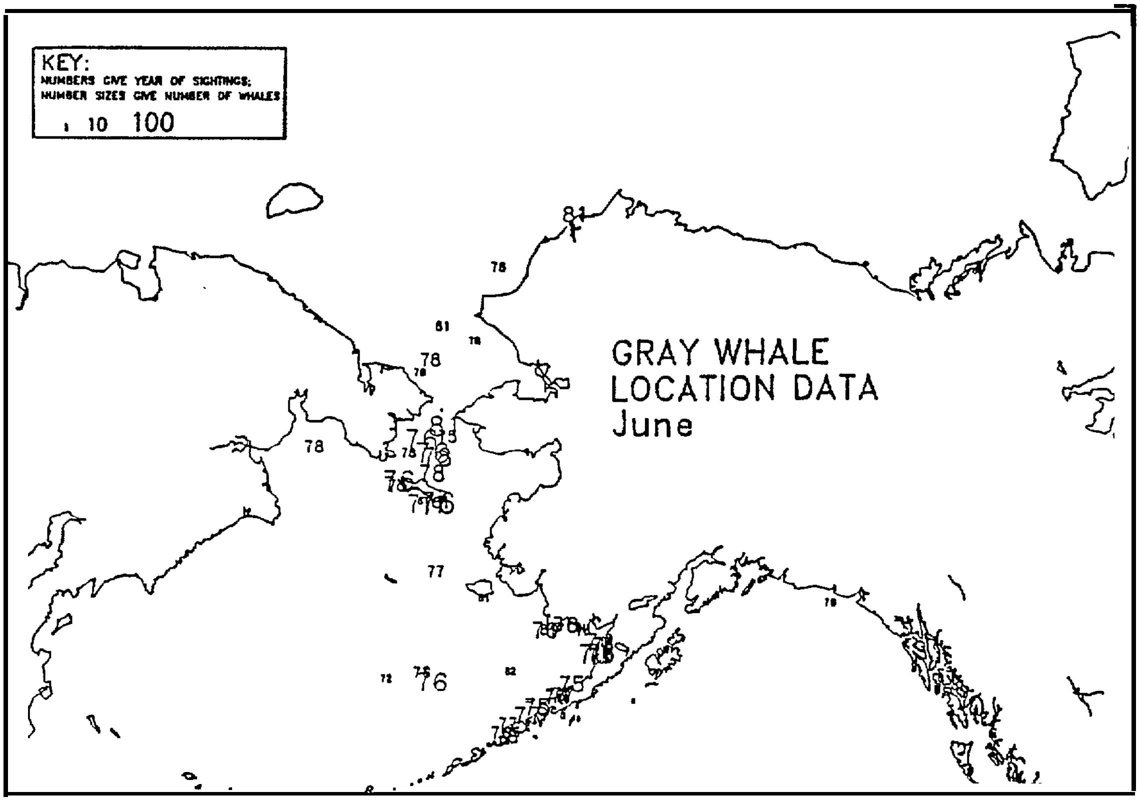



(a)

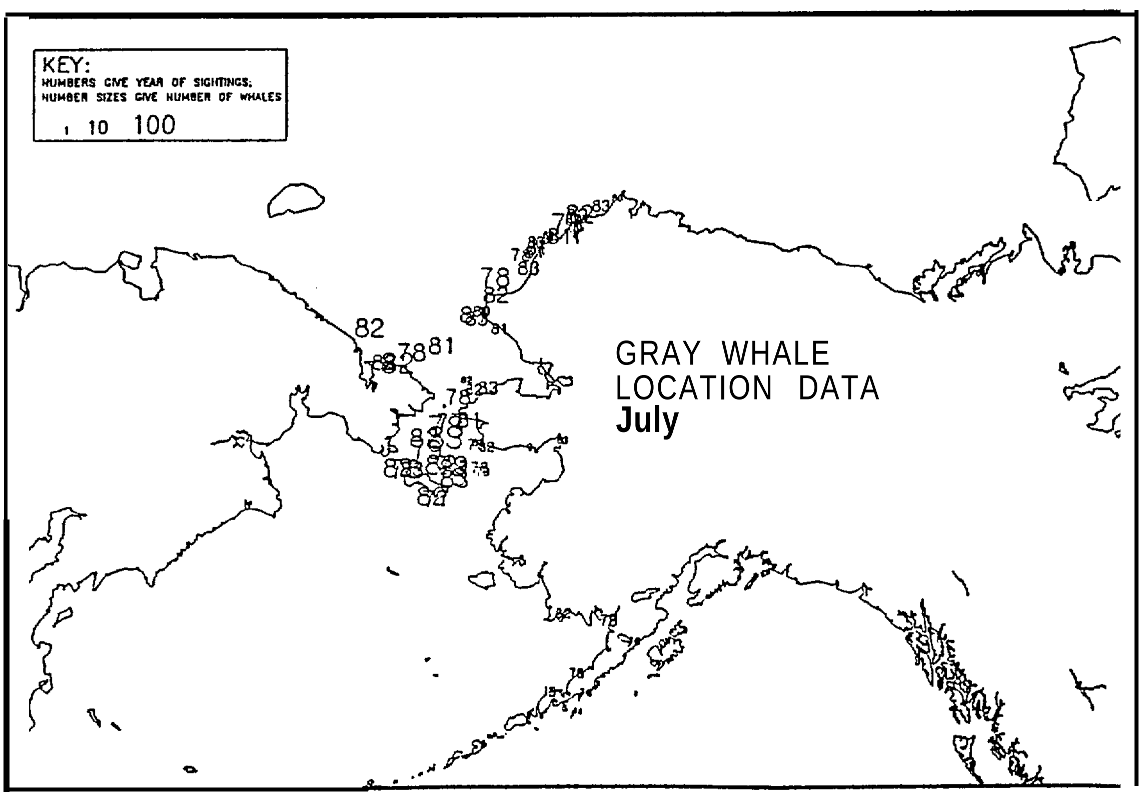



(b)

Figure 2-10a,b. Gray whale sighting data for a) April and b) May.

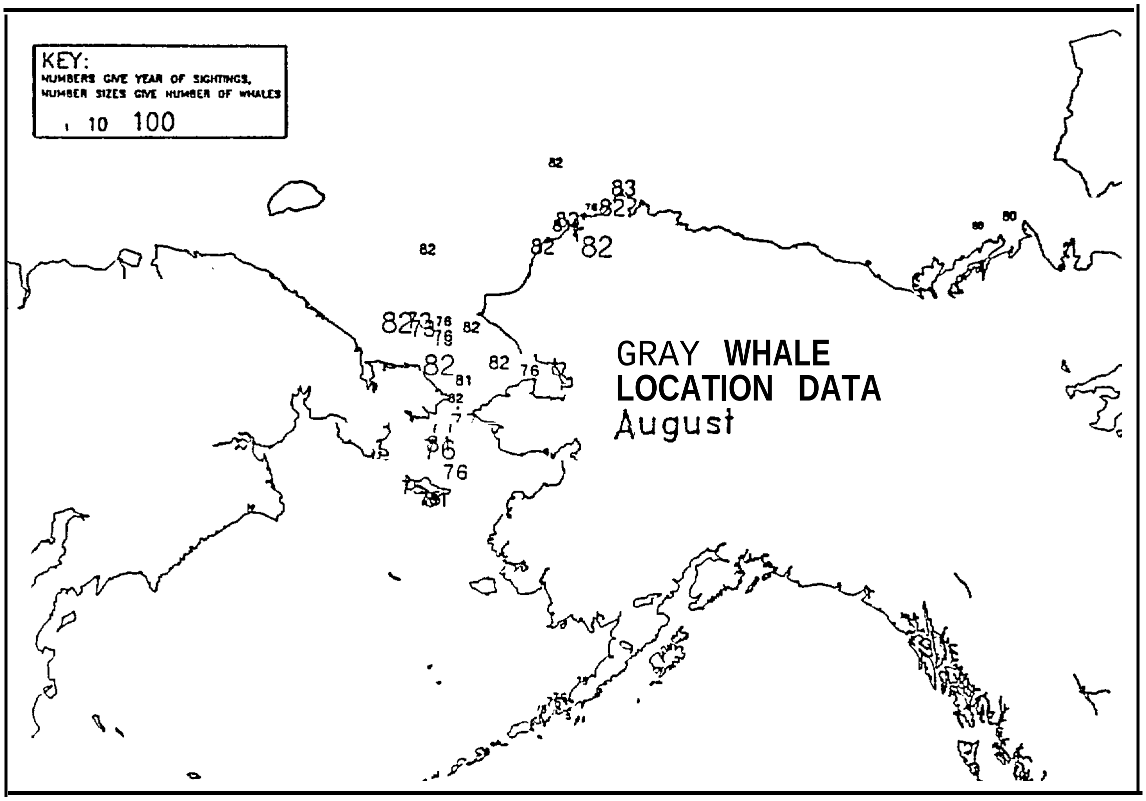



(c)

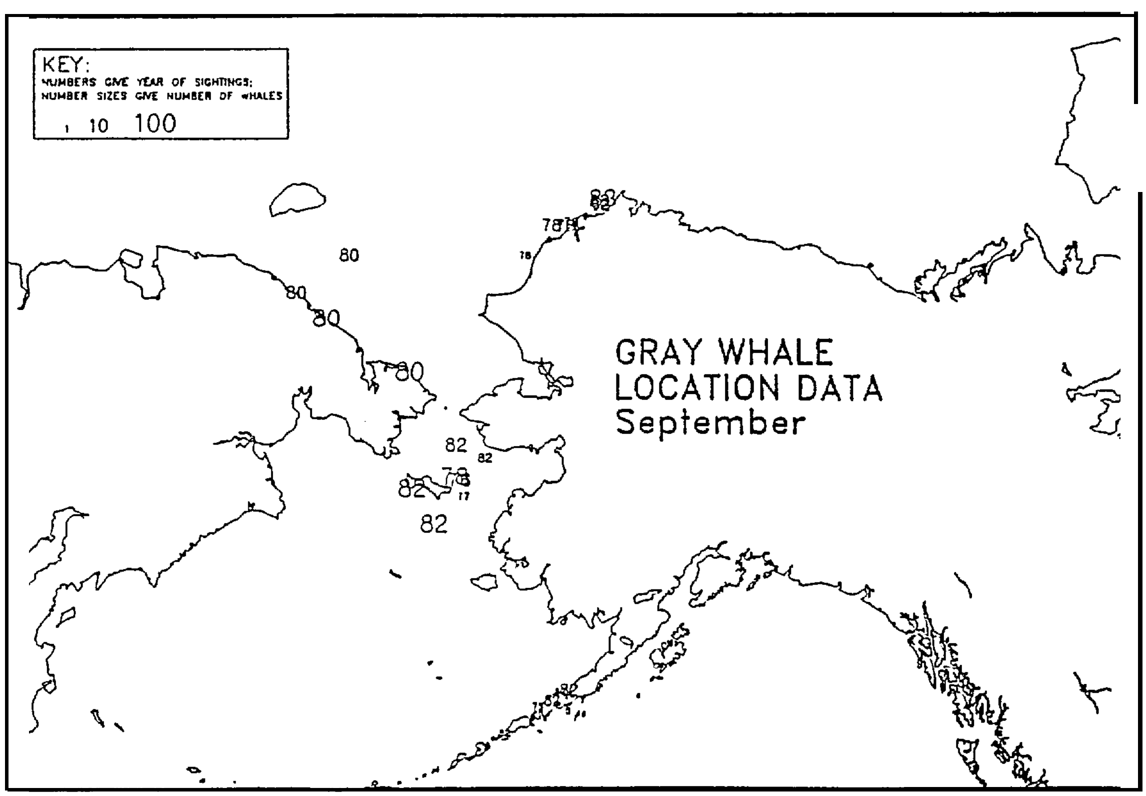



(d)

Figure 2-10c, d. Gray whale sighting data for c) June and d) July.

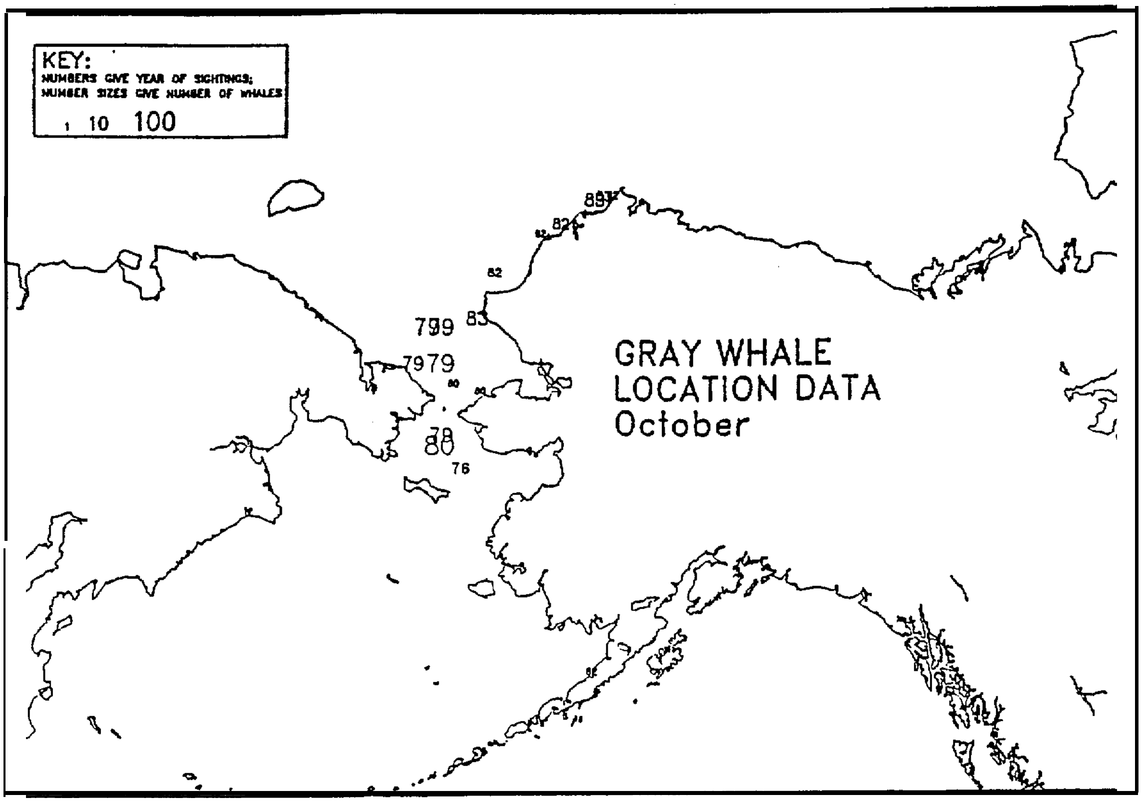



(e)

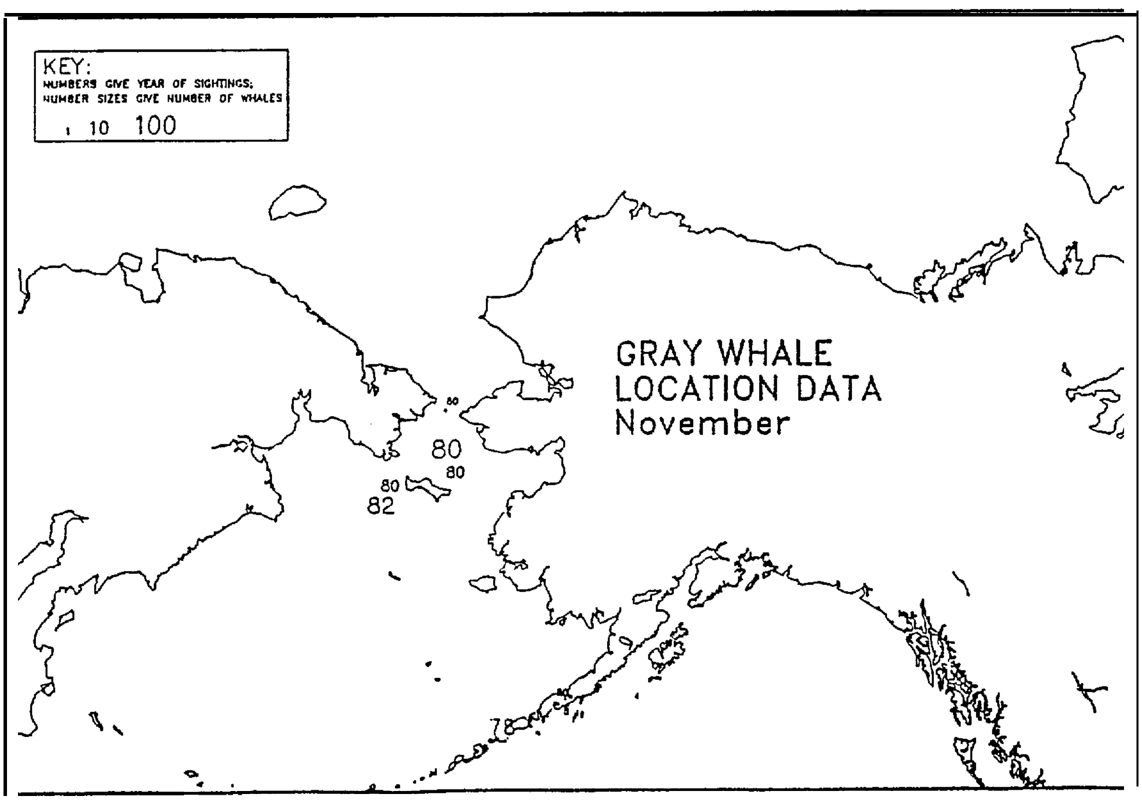



(f)

Figure 2-10e, f. Gray whale sighting data for e) August and f) September.




(g)




(h)

Figure 2-10g, h. Gray whale sighting data for g) October and h) November.

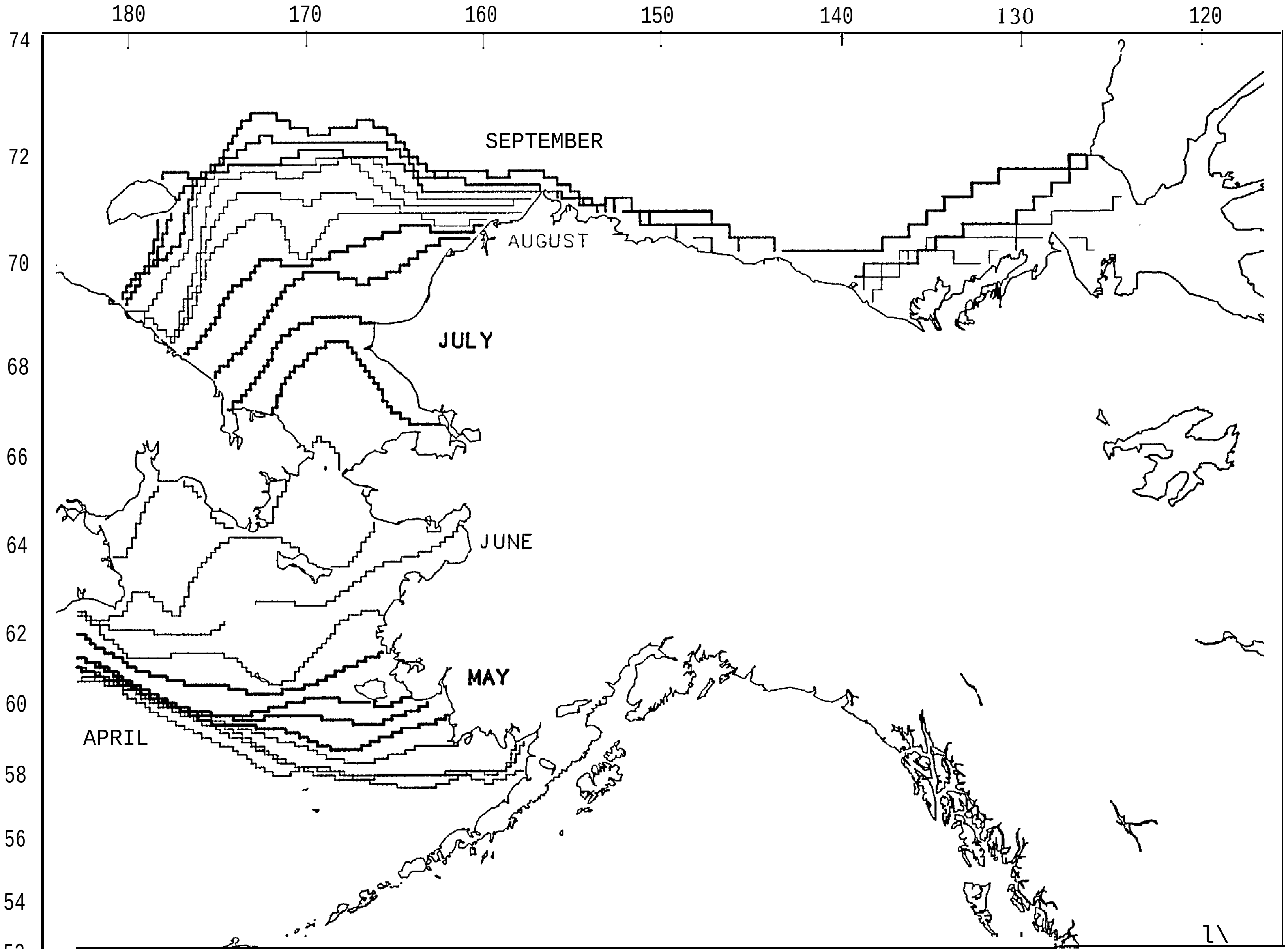



Figure 2-ha. Modeled summer ice edge locations for a normal ice year (50% probability of occurrence) .

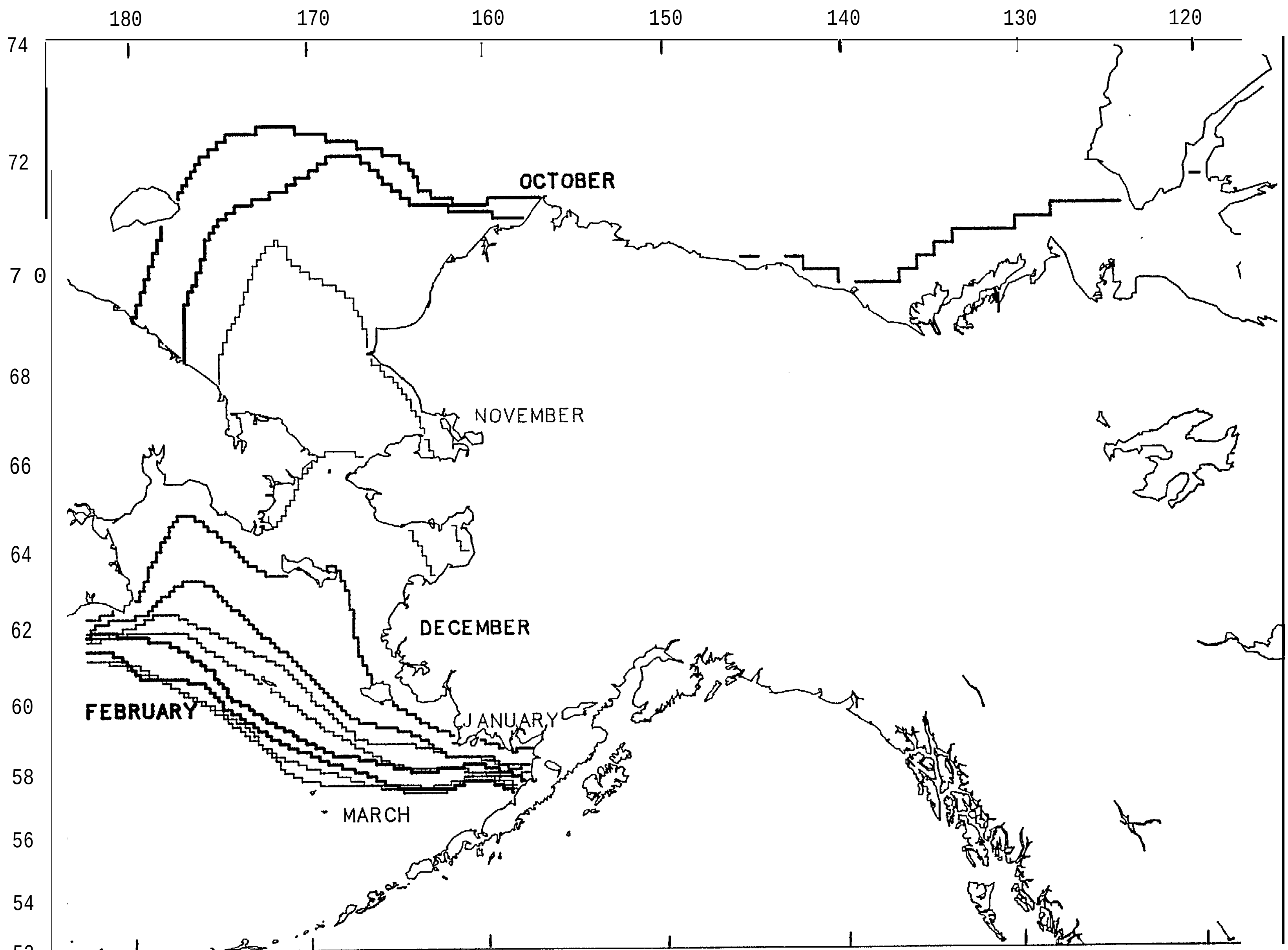



Figure 2-11b. Modeled winter ice edge locations for a normal ice year (50% probability of occurrence) .

allows the modeled whales to reach, but not exceed, the maximum observed swimming speeds of southbound gray whales. Once in open water, they resume travel at normal speeds.

The mean migration path for the gray whales is shown in Figure 2-12. In some areas, only limited data are available to substantiate the migration route, In the spring, migration is largely controlled by the presence of ice. A lack of survey effort in the fall is responsible for no sightings between Nunivak Island and Unimak Pass, so the migration route across Bristol Bay can only be hypothesized. Surveys are planned for Bristol Bay during the fall of 1986, but no data are yet available to substantiate a migration route. Due to data limitations, the results of the polynomial curve fit to the sighting data were too inconclusive to be used. The migration route was therefore developed by placing attractor points sequentially along the hypothesized route, using sighting data assembled by Reed et al (1984) and supplemented by published sources (Braham, 1984; Rugh, 1984; Gill and Hall, 1983). For comparison, Figure 2-13 shows the migration routes hypothesized by various other researchers.

An example simulation was run with gray whales entering Unimak Pass continuously from April 1 to June 1, peaking on April 20 and May 20. A total of 141 whale points was used in the simulation. Figures 2-14a through 2-14h present monthly snapshots of the resultant distributions. The routes followed by 10 sample whale points are shown in Figure 2-15. These routes illustrate the variability in the migration pathways followed by the gray whale.

Observed gray whale densities from different seasons were used to calibrate the model. As with the bowhead whale model, the simulation was adjusted to attempt to achieve simulation densities within one standard deviation of the observed mean in as many areas as possible. When only one observation was available for a given region, the mean was assumed equal to the observed value, and a standard deviation was calculated as the average coefficient of variation times this estimated mean. Multiple years of data in a given area were available only in July, and, therefore, the average coefficient of variation of 1.1 calculated from the July data was used for each season to calculate expected standard deviations. Note that this value is equivalent to that calculated from bowhead observations, indicating similar variability in density estimates between the two species.

To calculate modeled whale densities, the gray whale population which passes through Unimak Pass was assumed to total about 17,000 animals. This number is the upper bound of the 11,000-17,000 animals estimated by Rugh (1984). The simulation employed 141 points, so each whale point therefore represents 1.20 whales . Effort-corrected density data for gray whales is sparser than that for bowhead whales. In no case are there more than 2

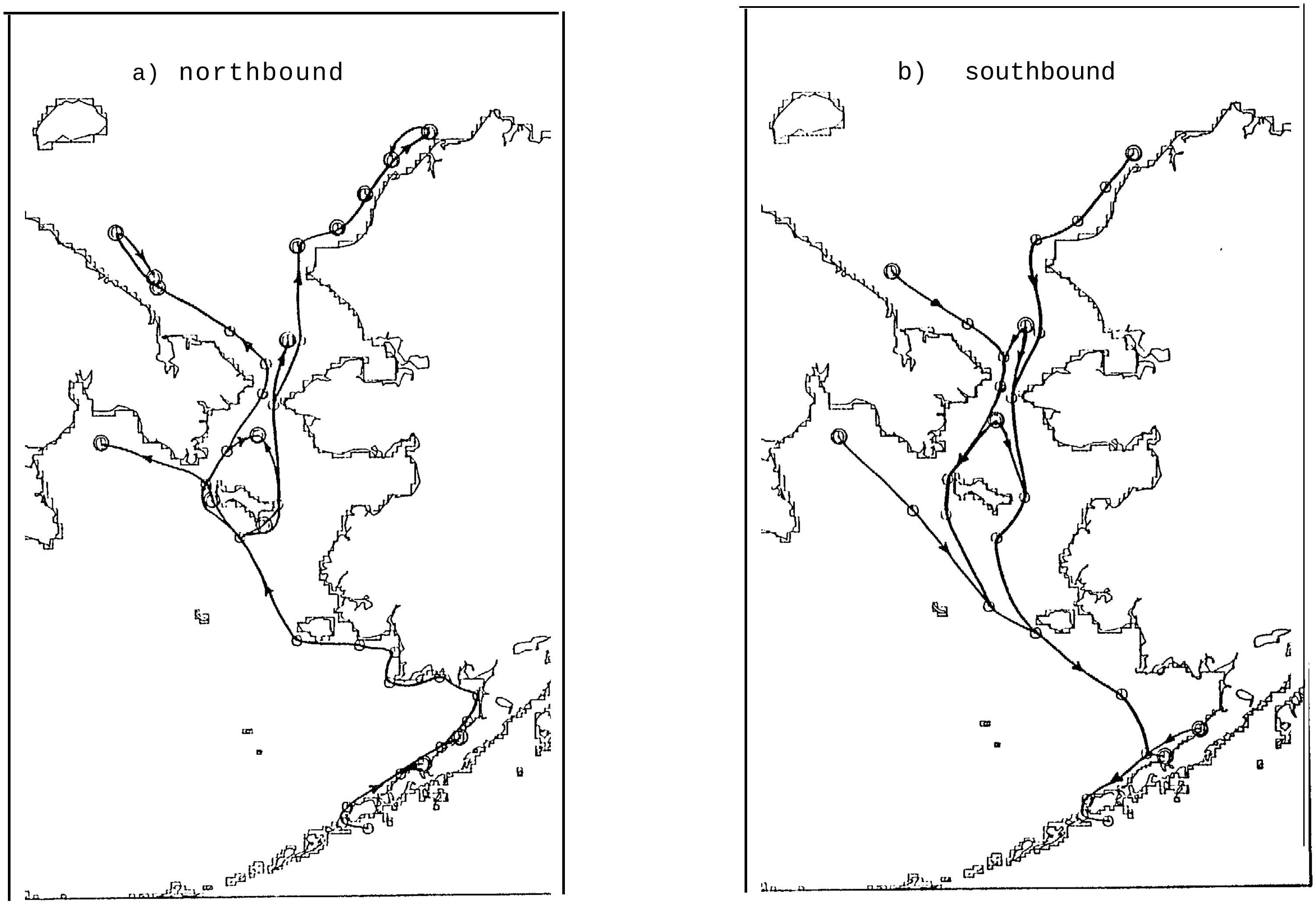



Figure 2-12. Mean pathways for simulated gray whale migration, showing location of attractor points and model grid. Hold points are shown with a double ring.

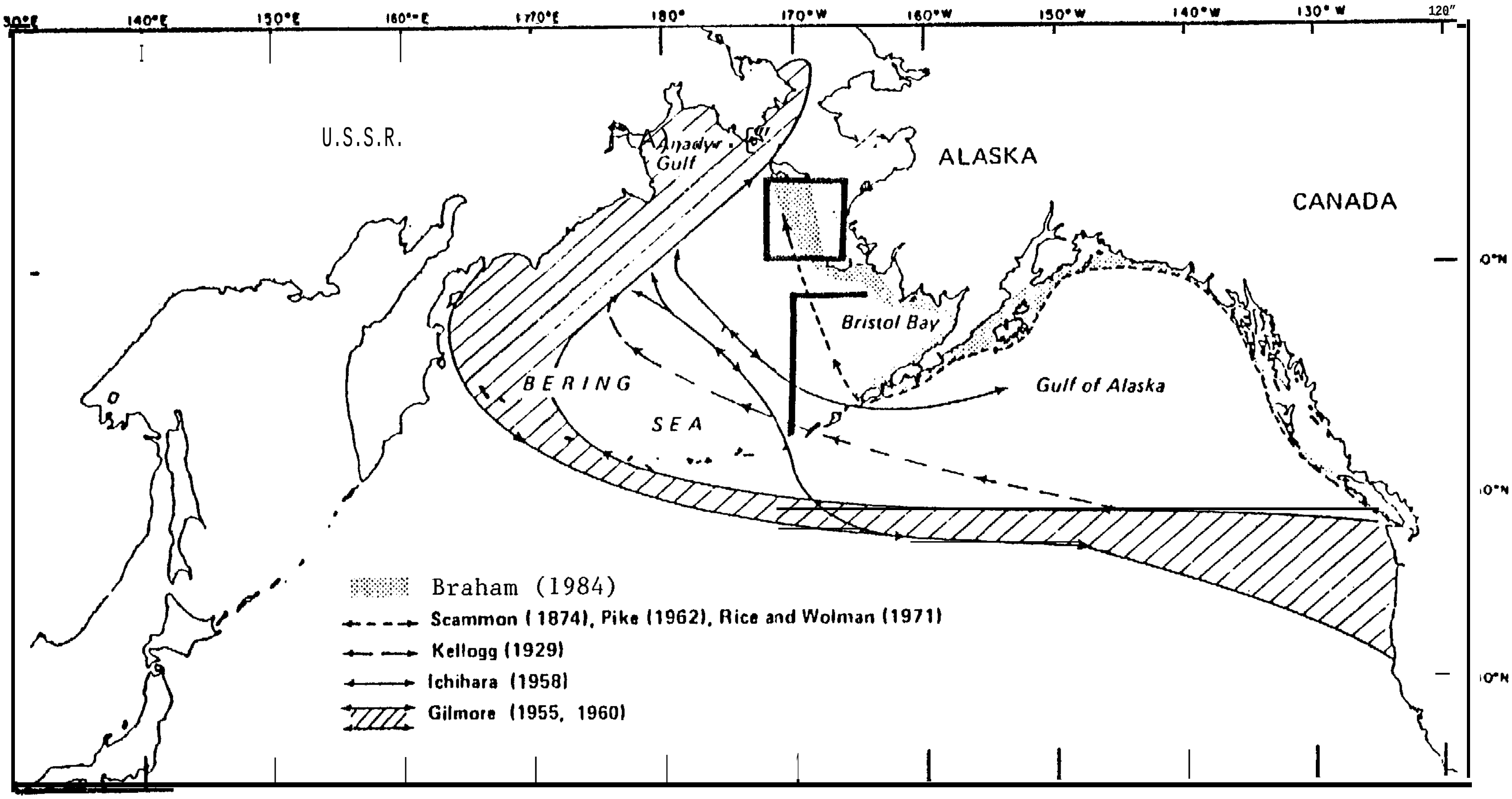



Figure 2-13. Gray whale migratory patterns hypothesized by other investigators (after Braham, 1984). Areas where little evidence exists to support the indicated corridor are boxed.

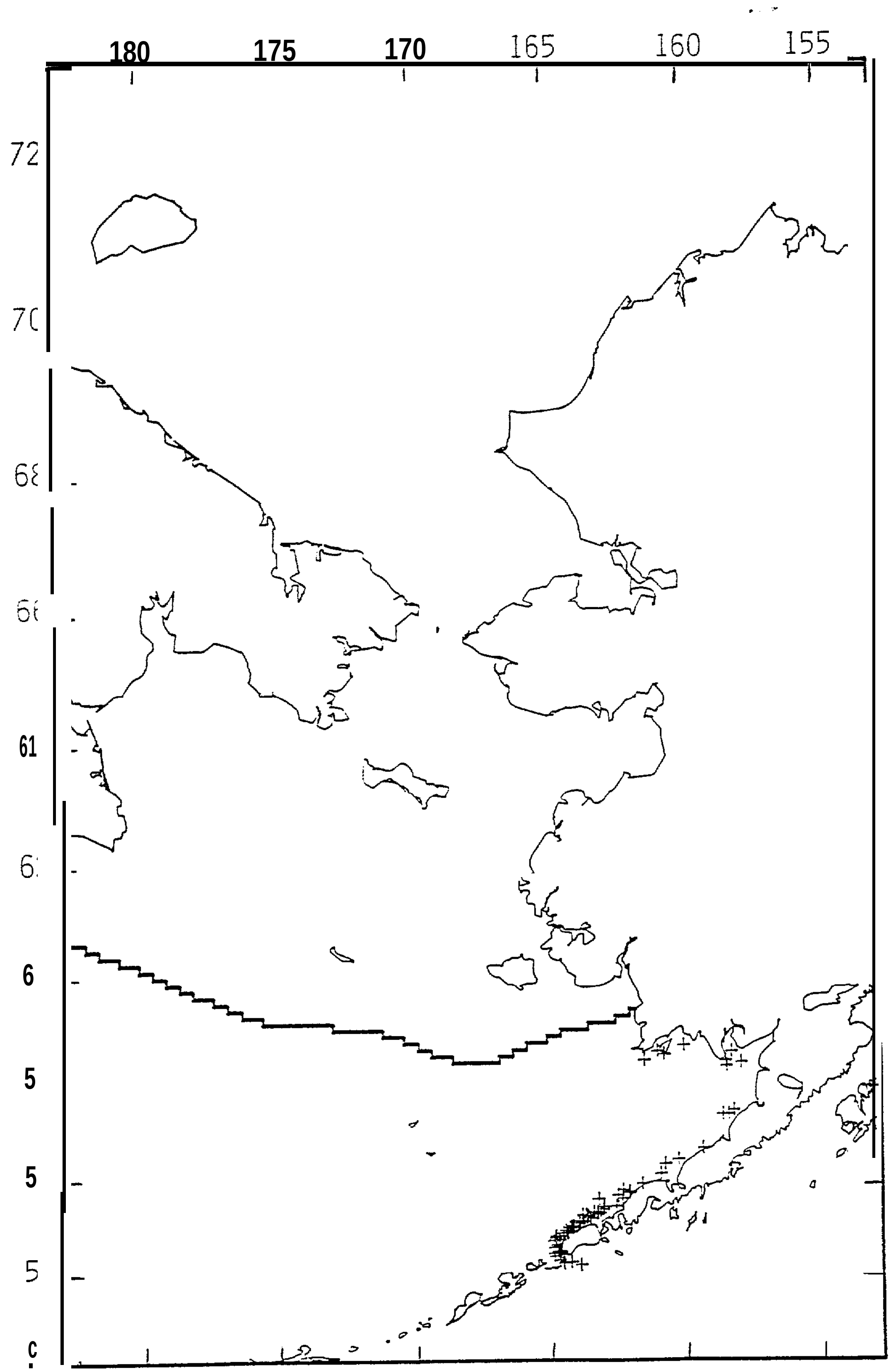



Figure 2-14a. Simulated distribution of 70 gray whale points on May 1. Heavy line is limit of ice edge.

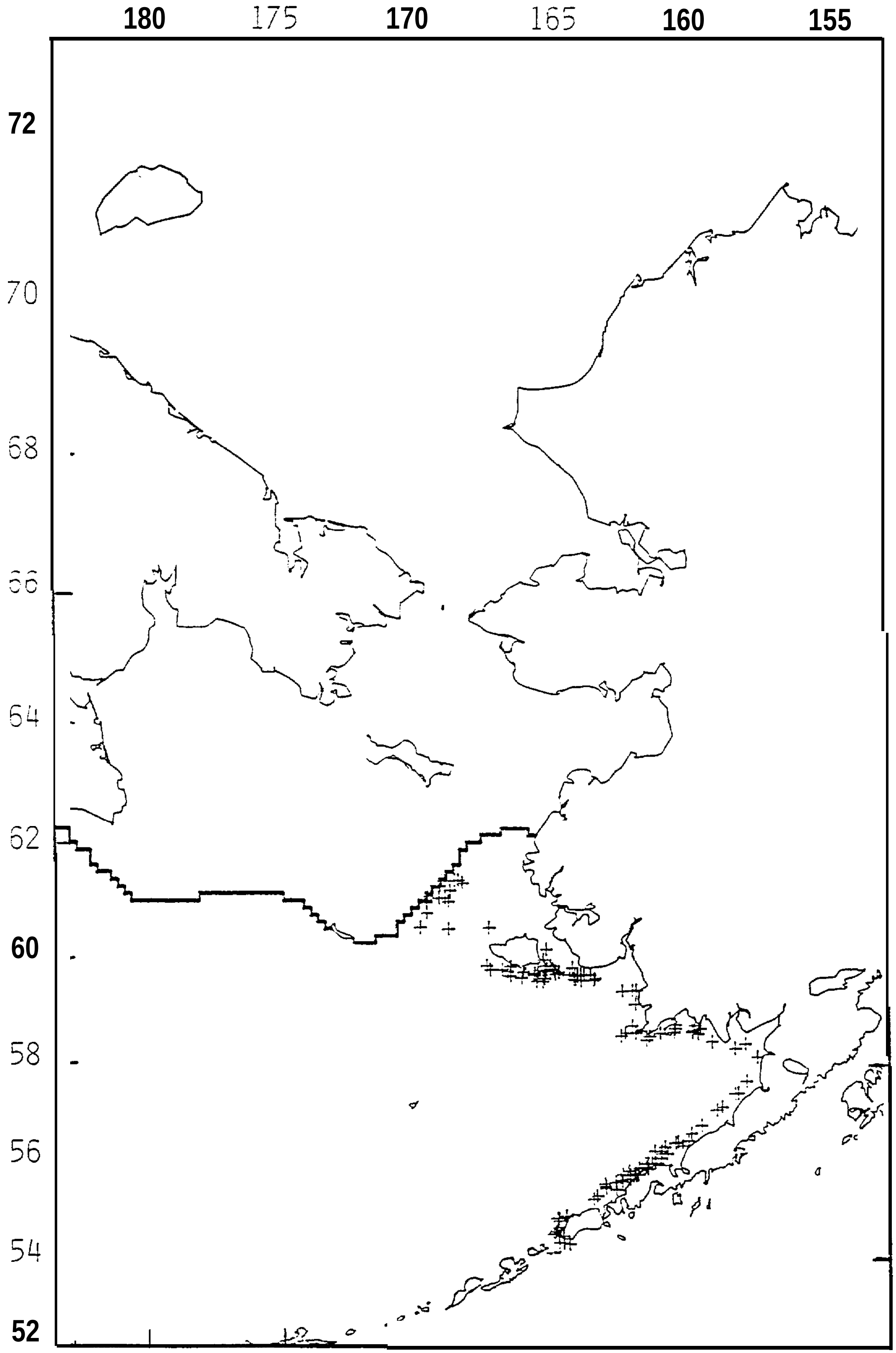



Figure 2-14b. Simulated distribution of 141 gray whale points on June 1. Heavy line is limit of ice edge.

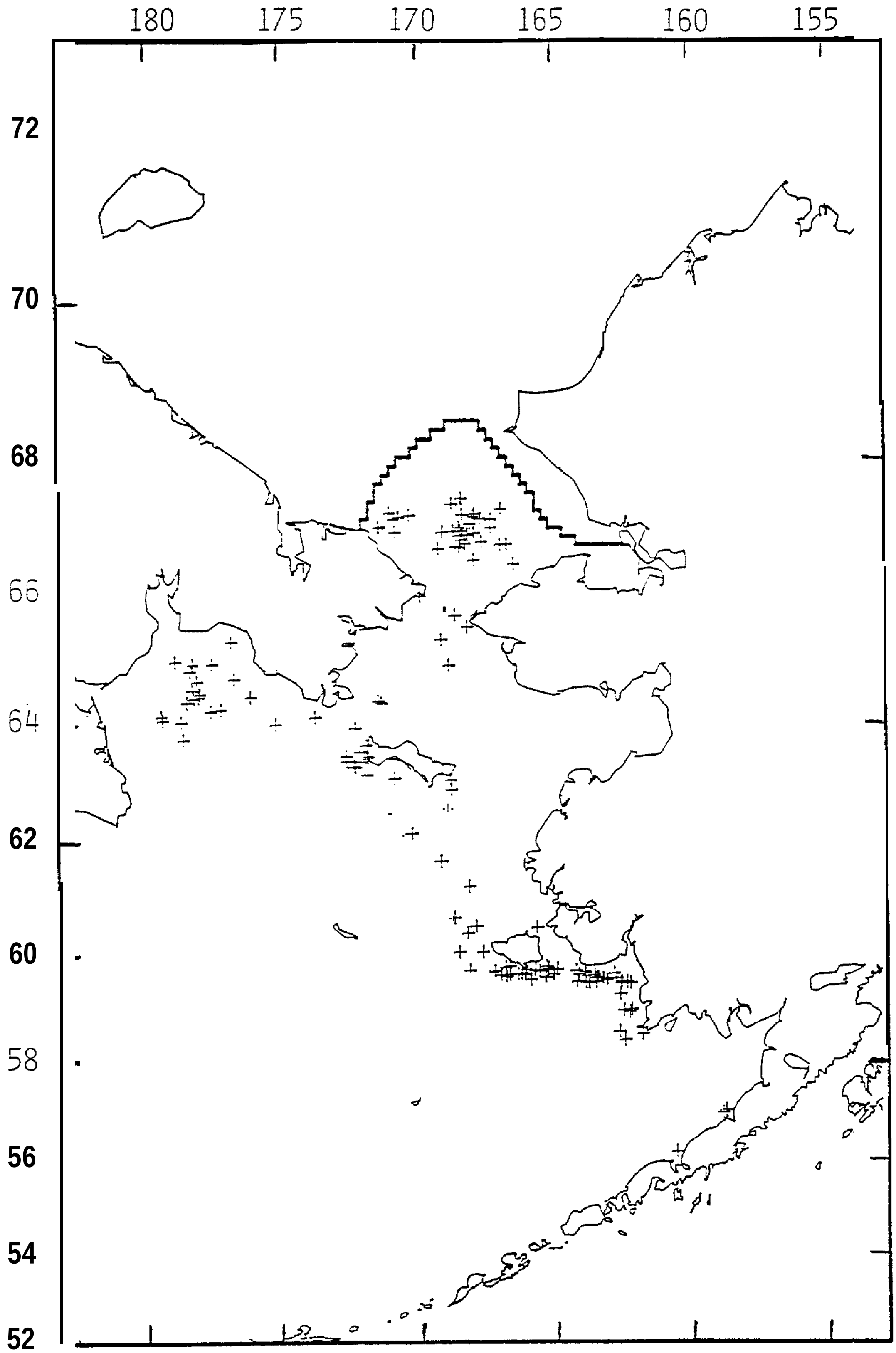



Figure 2-14c. Simulated distribution of 141 gray whale points on July 1. Heavy line is limit of ice edge.

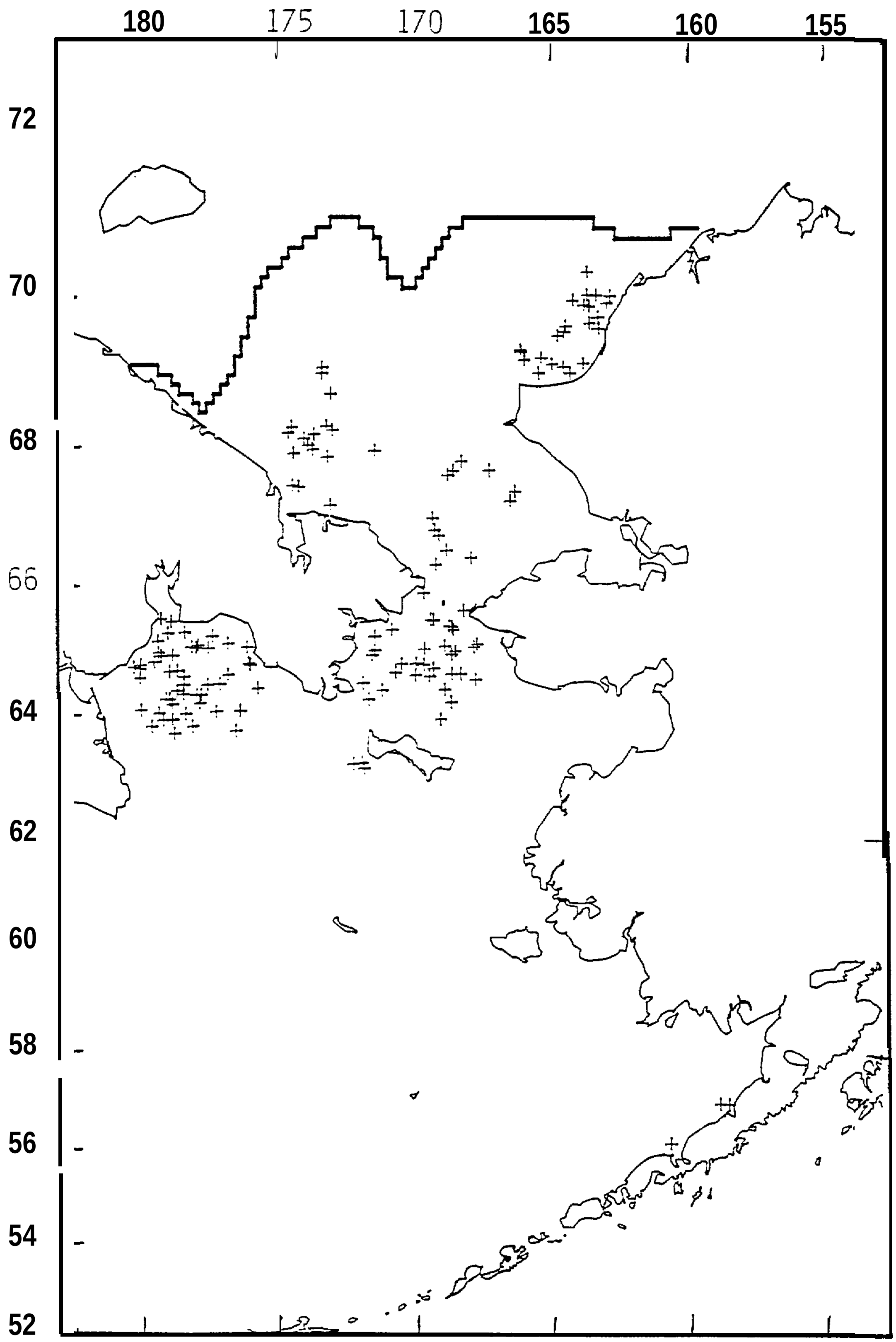



Figure 2-14d. Simulated distribution of 141 gray whale points on August 1. Heavy line is limit of ice edge.

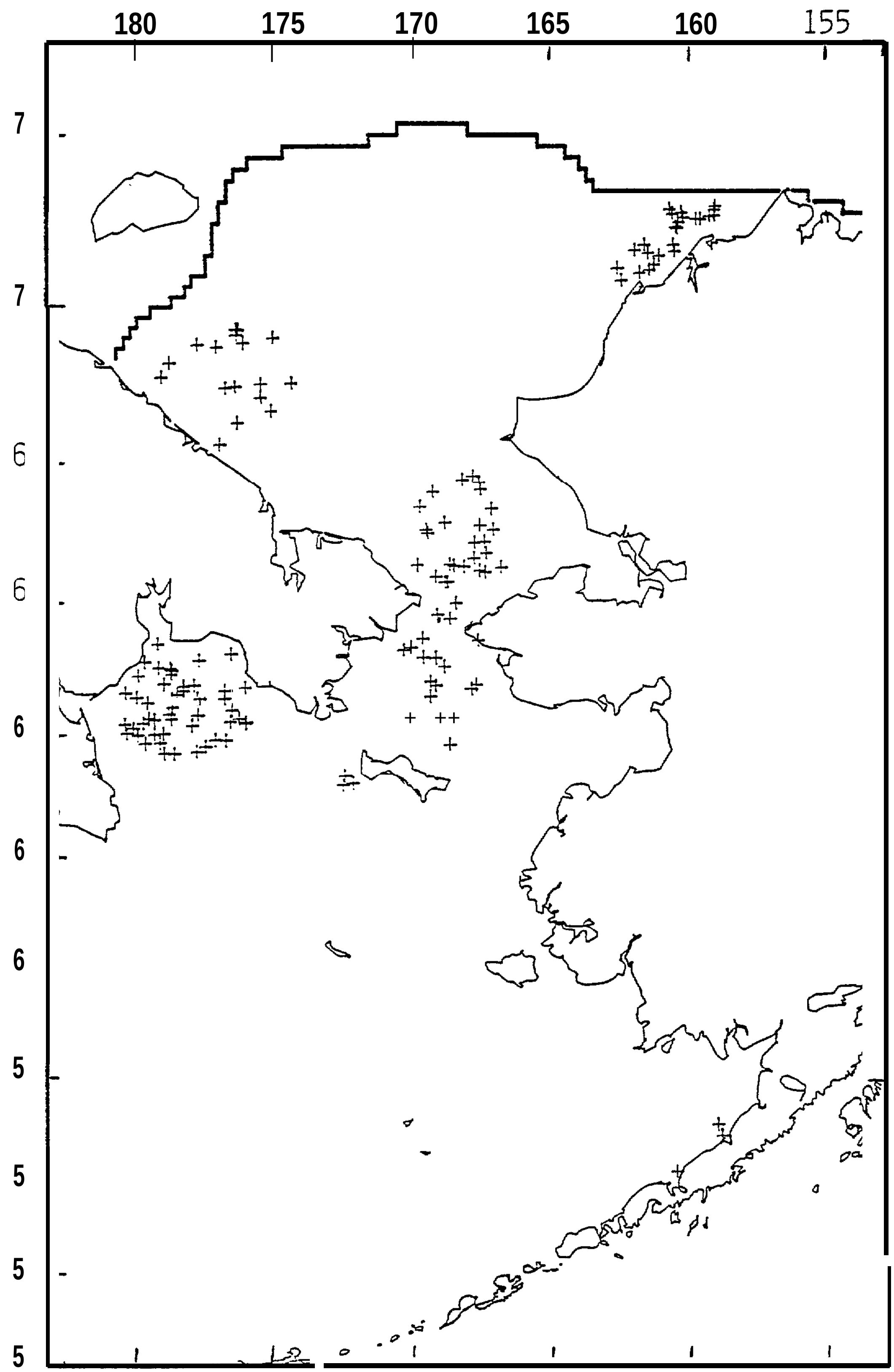



Figure 2-14e. Simulated distribution of 141 gray whale points on September 1. Heavy line is limit of ice edge.

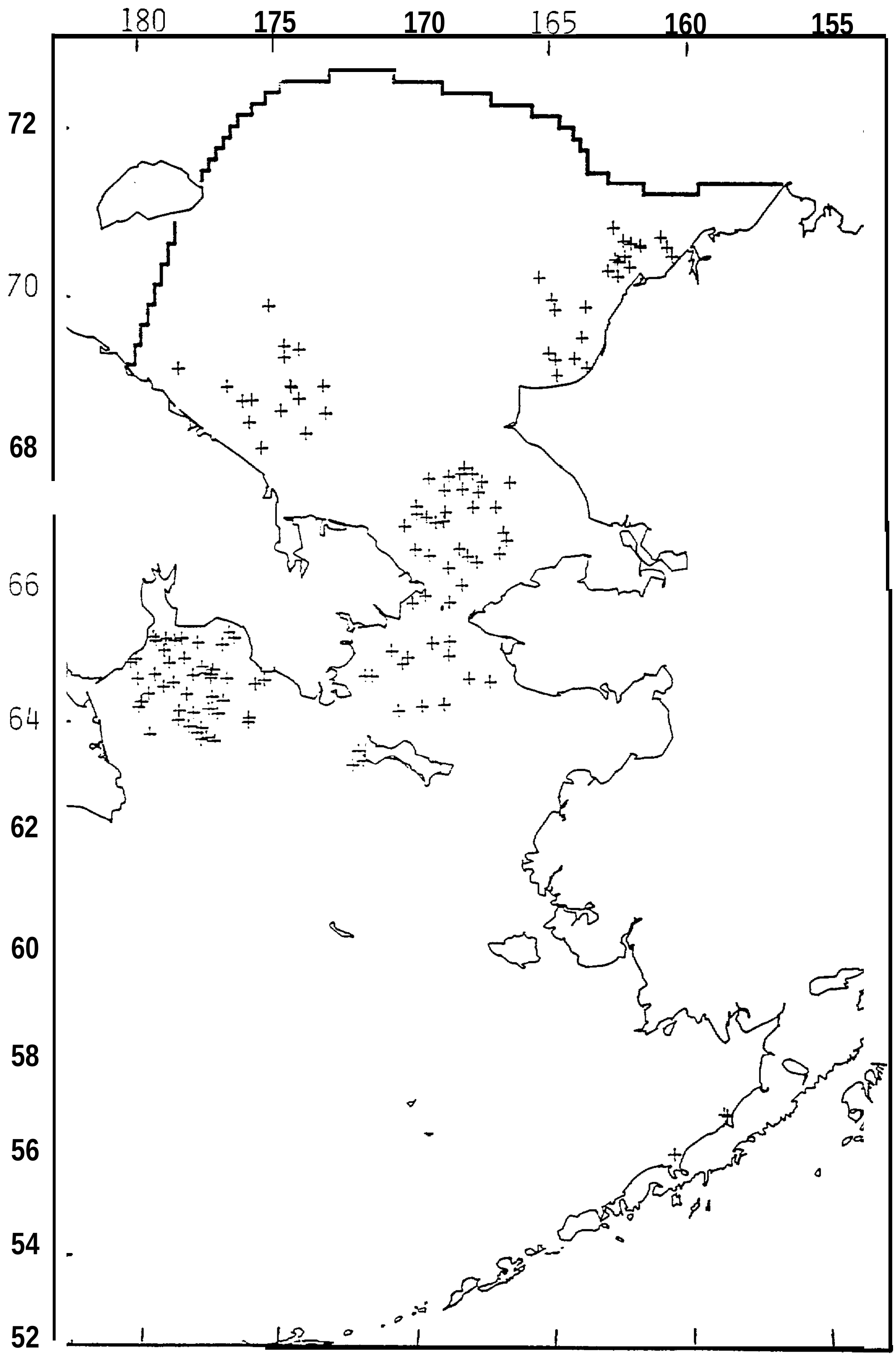



Figure 2-14f. Simulated distribution of 141 gray whale points on October 1. Heavy line is limit of ice edge.

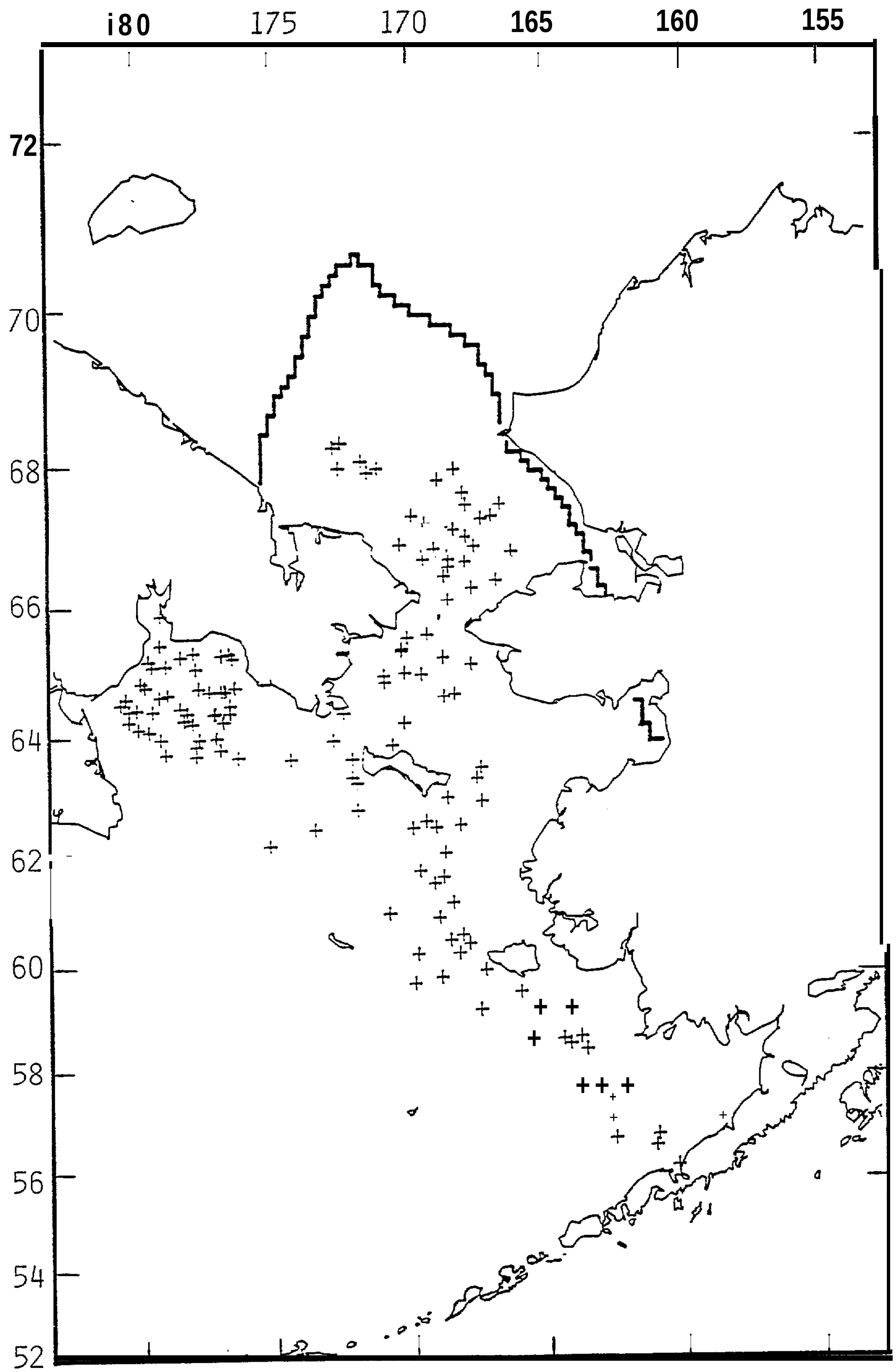



Figure 2-14g. Simulated distribution of 141 gray whale points on November 1. Heavy line is limit of ice edge.

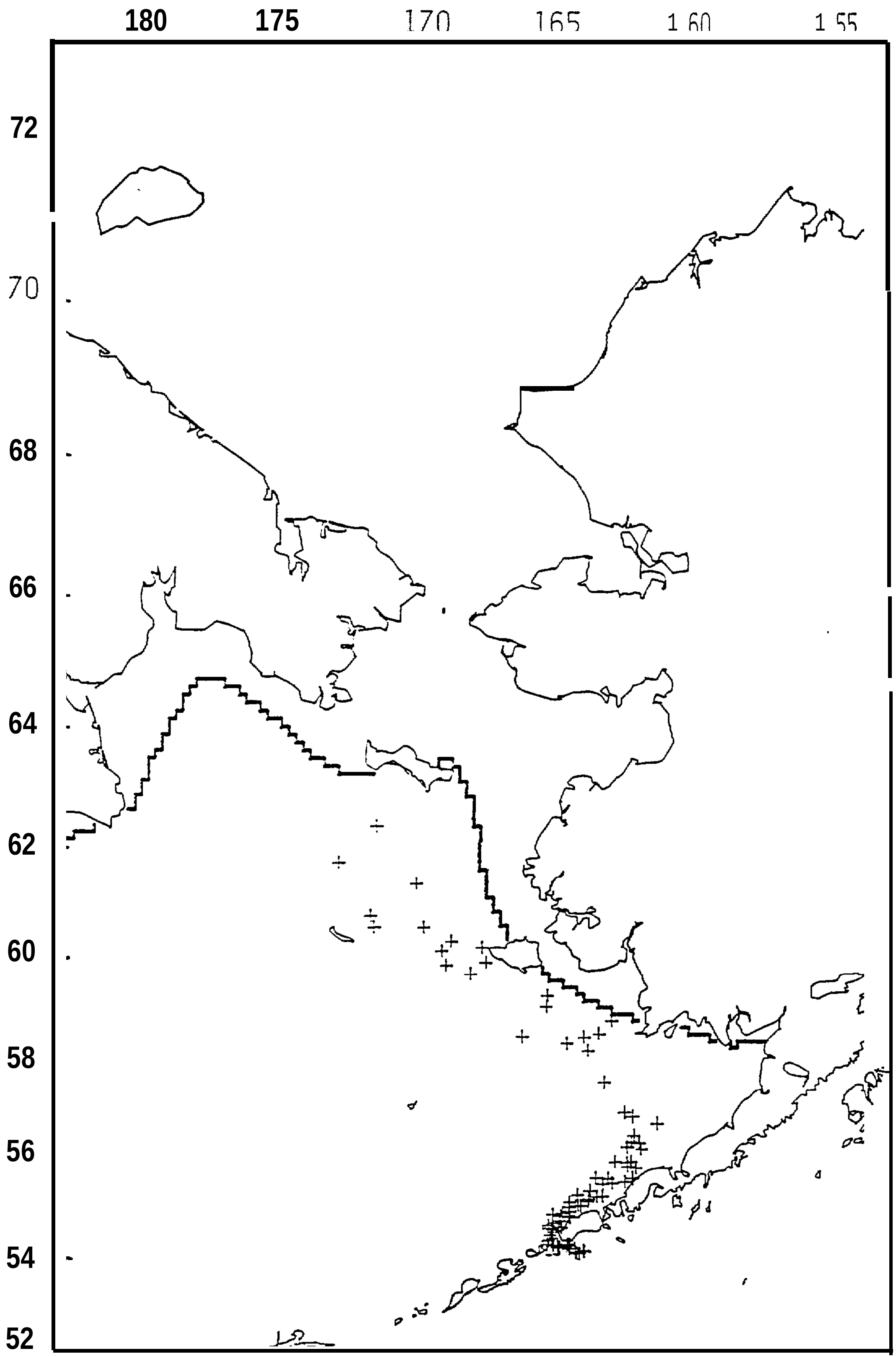



Figure 2-14h. Simulated distribution of 89 gray whale points on December 1. Heavy line is limit of ice edge.

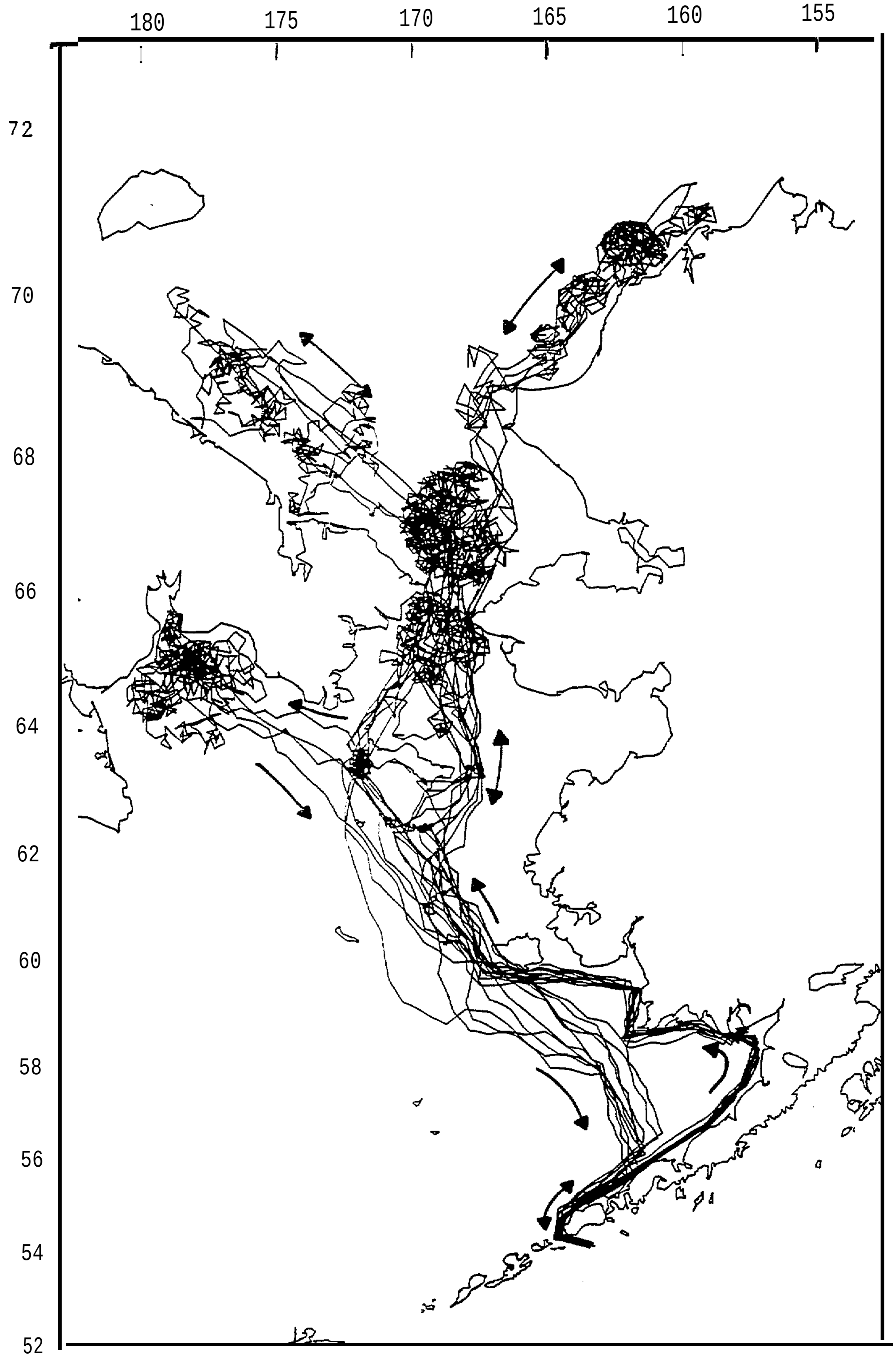
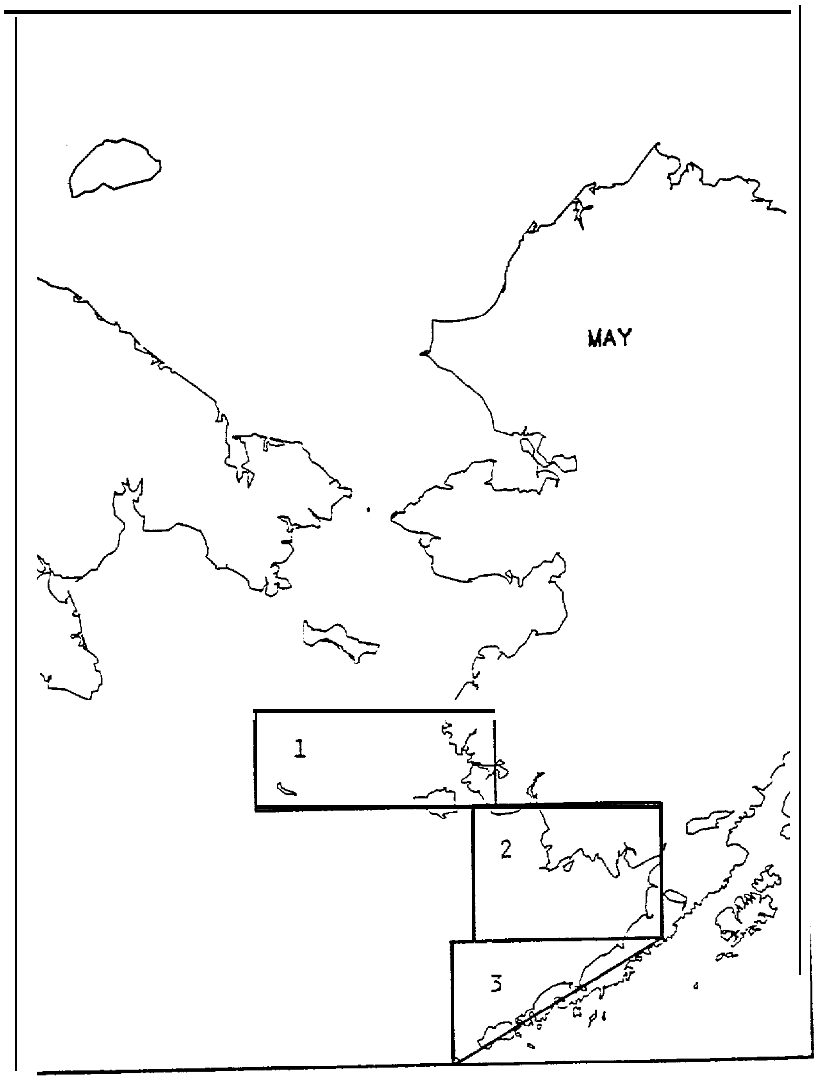



Figure 2-15. Routes followed by 10 gray whale points during simulated migration in the Bering and Chukchi Seas.

years of density data available for any given region and season. Therefore, a truly representative picture of average gray whale distribution cannot be gained from the data. Cbserved and simulated whale densities are presented in Figures 2-16a through 2-16d. The observed densities in Figure 2-16a for the month of May come from surveys in 1982 only, and are therefore not necessarily indicative of an average distribution of whale density. Simulated densities are none the less within one (inferred) standard deviation of those observed.

Figure 2-16b presents the comparison of observed and simulated densities for July. Only in Areas 1, 11, 12 and 15 do the observed and simulated densities differ by more than one standard deviation. Area 1, south of St. Lawrence Island, has a 0.0 whales/$km^2$ observed density based on one year's survey. Since many gray whales gather off Southeast Cape and Gambell to feed early in the summer (Johnson and Nelson, 1984; Braham, 1984), the density estimate is probably not representative of typical conditions. Similarly, Area 15 in the central Chukchi Sea includes part of a major feeding area (Marquette and Braham, 1982), as well as comprising part of the migration route for animals heading for the Alaskan Chukchi coast to feed. Its observed density of 0.0 whales/$km^2$ also appears anomalous. The simulated density in Area 11 is low and is therefore probably not significantly different from the observed dens i ty since observers could easily miss sighting sparse numbers of whales. Area 12 includes a substantial part of the central Chukchi Sea feeding area, but observed density estimates are relatively low. To bring the simulated density into better agreement with the observed density, a large percentage of the simulated whales summering in the Chukchi Sea would need to be diverted into other areas. Since agreement is already quite good in the rest of the surveyed areas, most of the animals would have to be sent into Soviet waters. At this time, sufficient data is not available to conclusively determine whether this is the correct approach. The percentage of the gray whale population which summers west of the International Date Line is not known. An integration of whale densities over the areas surveyed shows that the July surveys account for slightly more than 7000 whales, or about 40% of the population. Large numbers of animals have been reported in Soviet waters (Berzin, 1984). 'L'he density estimates for the Chirikov Basin for July and September were carried out under good conditions, so it appears probable that the whales are in Soviet waters.

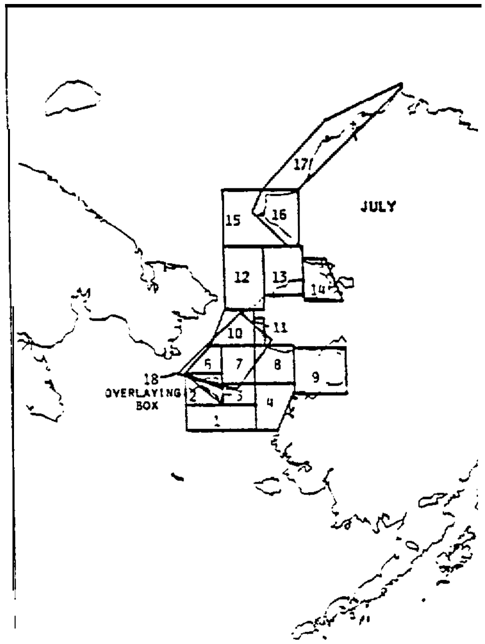
The observed density used in Figure 2-16c is taken from a single survey which spanned two days. This density cannot, therefore, be considered representative of typical September distributions. The simulated density for this area is slightly more than one (inferred) standard deviation from the mean, which may be considered acceptable given the limitations of using a single short term observation for comparison.




| Survey Area | Number of observations | Observed Density * Mean | Observed Density * Std. Dev. | Simulated Mean Density * | Number of std. devs. from the observed mean |
|---|---|---|---|---|---|
| 1 | 1 | .06900 | .07590 | .00539 | -0.8 |
| 2 | 1 | .06900 | .07590 | .07135 | 0.0 |
| 3 | 1 | .06900 | .07590 | .05081 | -0.2 |

*Density in whales/$km^2$

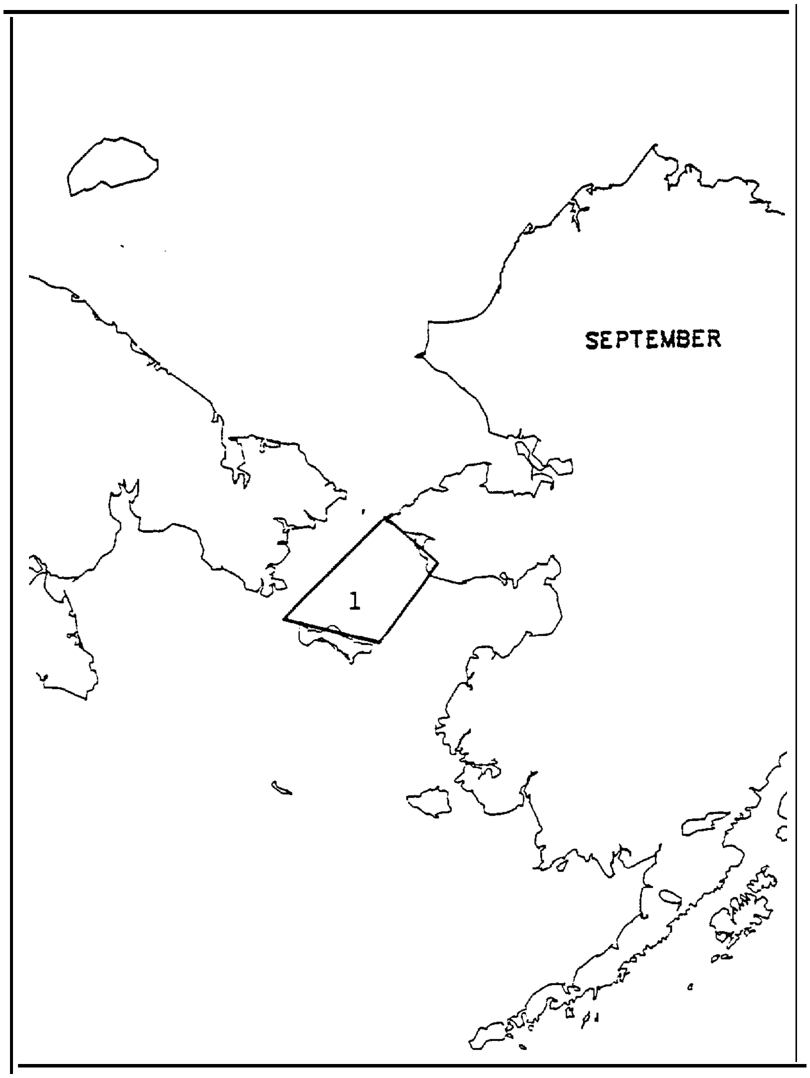
Figure 2-16a. Comparison of observed and simulated gray whale densities for May.




| Survey Area | Number of Observations | Observed Density * Mean | Observed Density * Std. Dev. | Simulated Mean Density * | Number of std. devs. from the observed mean |
|---|---|---|---|---|---|
| 1 | 1 | 0.0 | 0.0 | .02609 | + |
| 2 | 1 | .09200 | .10120 | .08771 | 0.0 |
| 3 | 2 | .01500 | .02121 | .03345 | +0.9 |
| 4 | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5 | 1 | .01050 | .01155 | .00314 | -0.6 |
| 6 | 2 | .03915 | .04504 | .02952 | -0.2 |
| 7 | 2 | .05700 | .06223 | .03702 | -0.3 |
| 8 | 2 | .00060 | .00085 | .00025 | -0.4 |
| 9 | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | 2 | .07825 | .09298 | .05417 | -0.3 |
| 11 | 2 | 0.0 | 0.0 | .00148 | + |
| 12 | 2 | .00465 | .00417 | .05851 | +12.9 |
| 13 | 2 | .00670 | .00820 | .00302 | -0.4 |
| 14 | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| 15 | 1 | 0.0 | 0.0 | .66100 | + |
| 16 | 2 | .04550 | .02051 | .06355 | +0.9 |
| 17 | 1 | .12500 | .13750 | .04064 | -0.6 |
| 18 | 1 | .04120** | .04532 | .03391 | -0.2 |

* Density in whales/km$^2$
** Estimate corrected for submerged and/or missed whales
\+ A + with no following number indicates the simulated density is higher than observed, but the number of standard deviations from the mean could not be calculated.

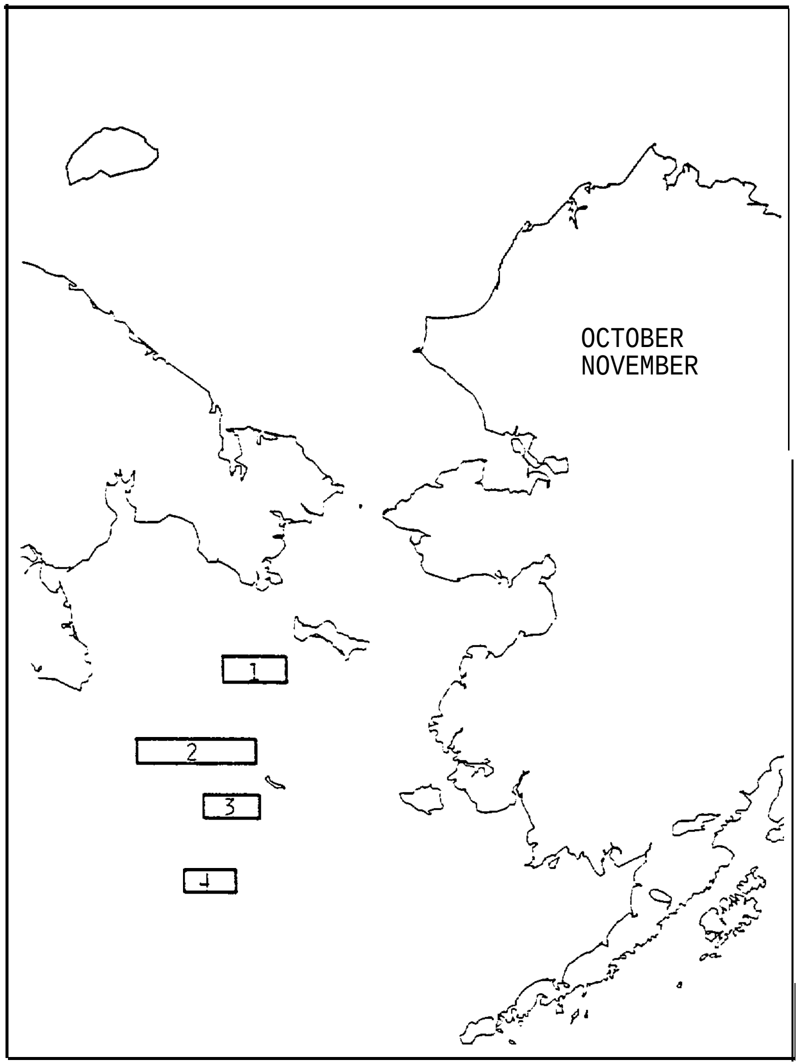
Figure 2-16b. Comparison of observed and simulated gray whale densities for July.




| Survey Area | Number of Observations | Observed Density * Mean | Observed Density * Std. Dev. | Simulated Mean Density * | Number of std. devs. from the observed mean |
|---|---|---|---|---|---|
| 1 | 1 | .01280** | .01408 | .02988 | +1.2 |

* Density in whales/$km^2$
** Estimate corrected for submerged and/or missed whales

Figure 2-16c. Comparison of observed and simulated gray whale densities for September.




| Survey Area | Number of Observations | Observed Density * Mean | Observed Density * Std. Dev. | Simulated Mean Density * | Number of std. devs. from the observed mean |
|---|---|---|---|---|---|
| 1 | 1 | .00539 | .00593 | .01073 | +0.9 |
| 2 | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4 | 1 | 0.0 | 0.0 | 0.0 | 0.0 |

* Density in whales/$km^2$

Figure 2-16d. Comparison of observed and simulated gray whale densities for October-November.

Simulation results for October/November (Figure 2-16d) are in good agreement with observations. Again, however, the observed data is from only one survey and is not necessarily representative of a typical year's distribution.

The egress of gray whales from the Bering Sea typically spans a two month period beginning early in November, peaking in late November and early December (Rugh, 1984). The simulation replicates this pattern (Figure 2-17) and shows reasonable agreement with census counts taken at Unimak Pass. An F-test statistic was employed to test for equal means end variances of the day of passing through Unimak Pass between the observed and simulated gray whale populations. The simulation was compared with data from the years 1978 and 1979 (Table 2-3). In 1978 the largest number of whales was sighted, although the field season was shorter "than in 1979. At the 99% confidence level, the hypothesis of equal mean day of passing through Unimak Pass cannot be rejected for the model and the 1978 observations, 1979 observations and combined 1978-1979 observations (F = 0.0000002, 0.00002 and 0.000003, respectively). The variances cannot be accepted as equal at the 95% confidence level when comparing each individual year's variance with the simulated variance. However, when comparing the simulation and the combined 1978-1979 data, which includes year-to-year variability and may be more representative of a "typical" passage scenario, the variances are not significantly different at the 95% level (F = 1.0).

Table 2-3. Statistical comparison of modeled and observed distributions of gray whales migrating south through Unimak Pass.

| Data Source | Mean Julian Day of Passage | Standard Deviation | Number of Observations |
|---|---|---|---|
| 1978 Observations | 336 | 9.5* | 16,600 |
| 1979 Observations | 341 | 10.3* | 13,400 |
| Combined 1978 & 1979 | 339 | 9.9 | 30,000 |
| Model Simulation | 336 | 9.9 | 141 |

* Standard deviations are significantly different from model at 95% level (F=1.09, F=1.08, respectively).

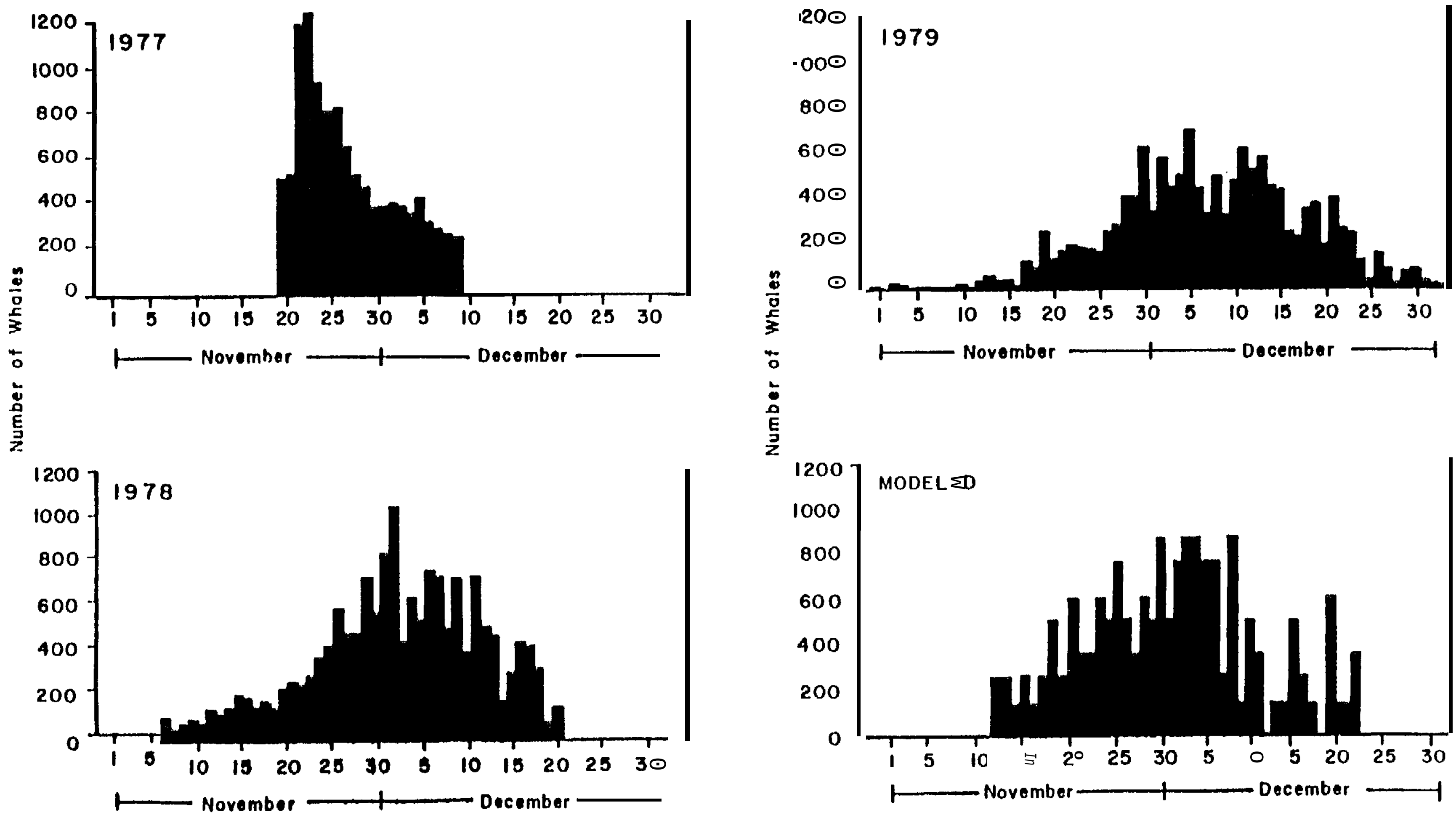



Figure 2-17. Observed and simulated distributions of gray whales migrating through Unimak Pass. Simulation assumes a population of 17,000 whales. Observed data after Rugh (1984).

## 2.4 Model Performance Summary

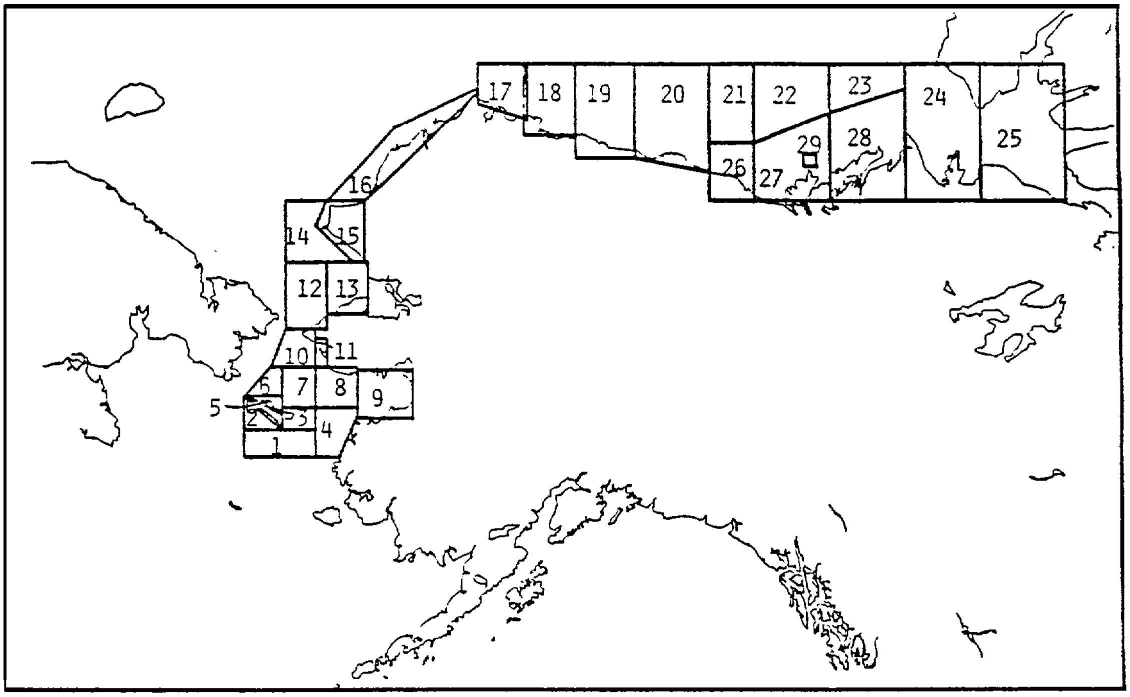
Computer models representing the migrations of bowhead snd gray whales in Alaskan, Canadian, and Siberian waters were conceptualized, programmed, and calibrated using actual observations of migrations. The models for both species are able to reproduce whale distributions which agree qualitatively and quantitatively 'with available sighting data (Reed et al, 1984). Simulated whale densities are generally within one standard deviation of the mean observed densities in most areas.

Model calibration was performed based on observed whale densities. The high degree of interannual variability typical of high latitude mar ine environments is reflected in the observed distributions of bowhead and gray whales; the standard deviation is greater than the mean observed density in almost all cases. Arctic environmental conditions limit the quantity and quality of the data available. The effort-corrected density data used for model calibration does not account for the entire population in any season. Simulated densities, when significantly different from the observations, always exceed the observed densities. Corrections for missed and submerged whales have been found to increase the estimated densities by as much as a factor of 8, and therefore greatly influence calibration of the model. These factors made model calibration somewhat difficult, but modeled whale distributions and movements compare favorably with the main body of observational data assembled to date for these two species.

Figures 2-18 and 2-19 summarize the results of model calibration using observed density estimates for the bowhead and gray whale migrations, respectively. The bowhead whale model achieves densities within one standard deviation of the mean observed density in 70% of the comparisons. For the gray whale model, 80% of the simulated densities are within one standard deviation of mean observed values.

The primary discrepancies between simulated and observed densities of the bowhead whale exist in the areas west of Pt. Hope and near Barter Island in April/May, in the Canadian Beaufort near the Mackenzie Delta and Tuktoyaktuk Peninsula and in Amunds en Gulf in July , August and September, and near Pt. Barrow in September/October. For the period November - March, bowhead whales are distributed among the hypothesized over-wintering areas. Data are not available to verify their densities and distribution.

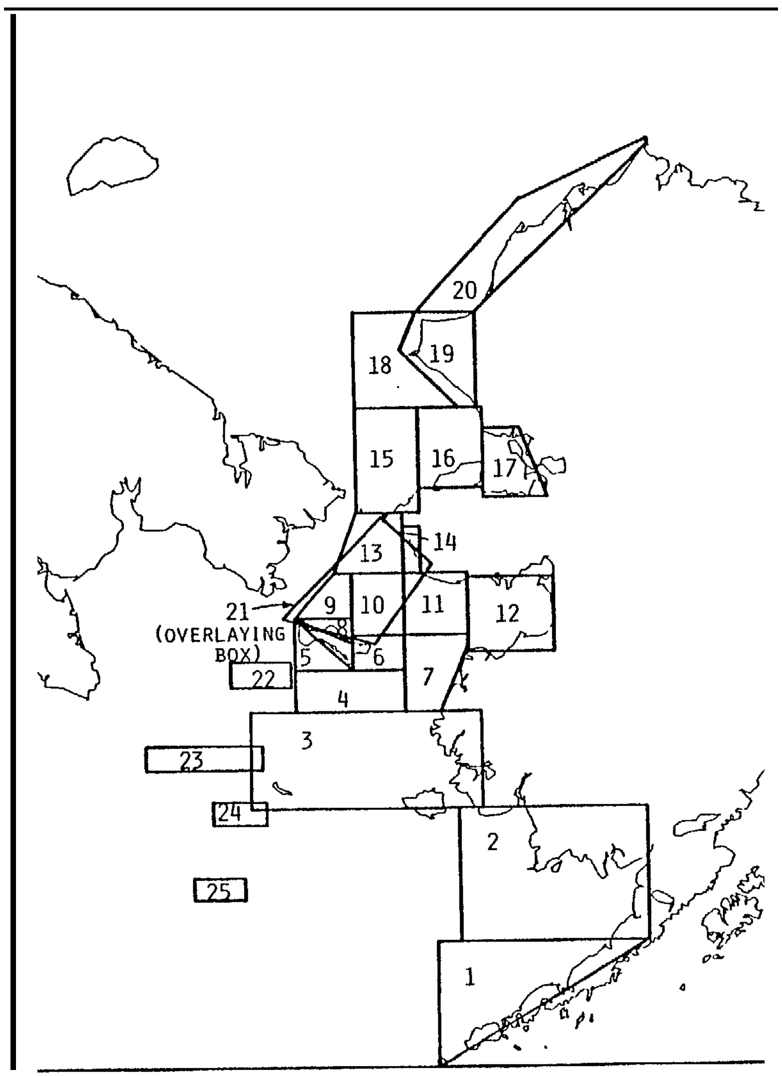
Major discrepancies between observed and simulated densities of the gray whale occur in July in the central Chukchi Sea from Cape Lisburne South to Bering Strait, and south of St. Lawrence Island. For the rest of the year, observed and simulated densities show acceptable agreement, although it must be noted that the




| Survey Area | April/May | July | August | September | September /October |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| 3 | + | | | | |
| 4 | + | | | | |
| 5 | | | | | |
| 6 | + | | | | |
| 7 | . | | | | |
| 8 | | | | | |
| 9 | | | | | |
| 10 | . | | | | |
| 11 | + | | | | |
| 12 | . | | | | |
| 13 | + | | | | |
| 14 | | | | | |
| 15 | . | | | | |
| 16 | . | | | | |
| 17 | + | | + | | |
| 18 | + | | + | | + |
| 19 | | | + | | |
| 20 | | | + | | + |
| 21 | | + | + | + | |
| 22 | | | + | + | |
| 23 | | | + | + | |
| 24 | | + | | + | |
| 25 | | + | | | |
| 26 | | | + | + | |
| 27 | | | | | |
| 28 | | | + | | |
| 29 | | + | + | | |

+ = simulated density within one standard deviation of observes mean density
- = simulated density outside one standard deviation of observed mean density

Figure 2-18. Summary of bowhead whale model performance.




| Survey Area | May | July | September | October/ November |
|---|---|---|---|---|
| 1 | + | | | |
| 2 | + | | | |
| 3 | + | | | |
| 4 | | | | |
| 5 | | + | | |
| 6 | | + | | |
| 7 | | + | | |
| 8 | | + | | |
| 9 | | + | | |
| 10 | | + | | |
| 11 | | + | | |
| 12 | | + | | |
| 13 | | + | | |
| 14 | | | | |
| 15 | | | | |
| 16 | | + | | |
| 17 | | + | | |
| 18 | | | | |
| 19 | | + | | |
| 20 | | + | | |
| 21 | | + | | |
| 22 | | | | + |
| 23 | | | | + |
| 24 | | | | + |
| 25 | | | | + |

+ = simulated density within one standard deviation of observed mean density
− = Simulated density outside one standard deviation of observed mean density

Figure 2-19. Summary of gray whale model performance.

observed densities from May, September and October/November are based on only one year of observation. Gray whales are not expected to be north of the Alaska Peninsula from early January through late March.

The areas noted above are those in which estimates of whale-oil spill interaction probabilities should be regarded with caution. However, since simulated densities are greater than observed densities for these areas in all cases, any error will be on the conservative side (i.e. , will result in overestimation of interaction probabilities).

3. Diving-Surfacing Model

A summary of the published data on the diving and surfacing of bowhead and gray whales was included in the Phase I report for this project (Reed et al, 1984). This information plus additional data acquired during this second phase of the project have been analyzed to develop stochastic diving-surfacing models. Table 3-1 summarizes the studies from which raw data were obtained (see also HMRI, 1985).

Initially, frequency distributions of the blow intervals from each Study were examined. Previous work had suggested that survivorship curves might be useful in detecting (Fagen and Young, 1978 ; Medved and Winn, 1984 ms) and modeling (Machlis, 1978) distributions of intervals. Consequently, we calculated survivorship curves for all data as well (HMRI, 1985). Both analyses indicated that the distributions of intervals between blows were modal, but that the distributions differed between studies and a simple two-behavior model (one for each mode in the data) of the type advocated by Machlis (1978) would not adequately describe the distributions.

To determine whether the heterogeneities we observed between data sets might be a consequence of bias toward short intervals in some studies, we looked for correlations between length of observation and mean and maximum blow interval, Biases were observed in the data for most studies. Method of observation seemed less important than survey conditions in the genesis of such biases according to one investigator (Wursig et al, 1984a). Biases due to length of observation affect the maximum dive time and the relative frequency of long dives.

To test for heterogeneities in the distributions of blow intervals among the different studies, we used a Kruskal-Wallis rank-sum test, and a multiple comparison procedure based on this test to make pairwise comparisons between the studies (Hollander and Wolfe, 1973) . We chose this procedure because large differences between the variances in different studies were observed, and also because the distributions were not approximately normal (see recommendations in Medved and Winn, 1984 ins).

Table 3-2 summarizes the results of this lamination for the bowhead whale. We found significant heterogeneities between the distributions of intervals collected on the westbound migration and all other studies, regardless of method. Studies conducted during the summering and eastbound phases of the migratory cycle did not differ significantly overall, although Wursig et al (1984a) report heterogeneities based on parametric tests between the two years of data they collected. Wursig's methods were sensitive to the bias against long dives in the intervals collected in 1983, and we feel this bias explains the differences in their results. Wursig et al (1984a) also reported differences in blow intervals between different categories of behavior and different age and sex classes. It is

Table 3-1. Sources of surfacing data used for model development.

| Reference | Observation Type | Species | Location |
|---|---|---|---|
| Harvey and Mate (1984) | telemetry | gray | Baja |
| Malme et al (1983) | vessel tracking | gray | S. Cal. Bight |
| Rugh (1984) Rugh (unpub) | landbased | gray | S. Cal. Bight |
| Kent et al (1982) | landbased | gray | S. Cal. Bight |
| Kent (unpub) | landbased | gray | S. Cal. Bight |
| Sumich (1983 ms) | landbased | gray | Pt. Loma |
| Rugh and Cubbage (1980) | landbased | bowhead | Pt. Barrow |
| Wursig et al (1982) | aerial tracking | bowhead | Beaufort Sea |
| Wursig et al (1983) | aerial tracking | bowhead | Beaufort Sea |
| Reeves et al (1983) | vessel tracking | bowhead | Beaufort Sea |

Table 3-2. Pairwise comparisons between studies using distributions of blow intervals for the gray whale, using a multiple comparison test based on the Kruskal-Wallis retied sum test; whole table significant ($H$ = 335.24, df = 8, $p$ < .01). Each cell in the table gives the difference between mean ranks and indicates significance (* signifies $P$ < .01). Sample size, and median, minimum and maximum blow interval are given for esch study.

| PHASE<br>SITE | WINTER<br>S1 | NORTHBND<br>UP | SUMMER<br>OR | SOUTHBND<br>PL | SOUTHBND<br>SC, '81 | SOUTHBND<br>SC, '83 | NORTHBND<br>YP1 | NORTHBND<br>YP2 | NORTHBND<br>YP3 |
|---|---|---|---|---|---|---|---|---|---|
| S1 | --- | | | | | | | | |
| UP | * 1538.83 | --- | | | | | | | |
| OR | * 1468.29 | 70.54 | --- | | | | | | |
| PL | * 2559.91 | * 1021.08 | 1091.62 | --- | | | | | |
| SC, '81 | * 1184.11 | 354.73 | 1091.62 | * 1375.80 | --- | | | | |
| SC, *83 | * 1485.47 | 53.36 | 284.18 | * 1074.44 | 301.36 | --- | | | |
| YP1 | 525.87 | * 2064.70 | 17.18 | * 3085.78 | * 1709.97 | * 2011.34 | --- | | |
| YP2 | 244.44 | * 1294.39 | * 1994.15 | * 2315.46 | 939.66 | * 1241.03 | * 770.31 | --- | |
| YP3 | 176.80 | * 1362.03 | * 1223.84 | * 2383.10 | 1007.30 | * 1308.67 | 702.67 | 64.64 | --- |
| *N* | 11070 | 717 | 372 | 670 | 284 | 1465 | 1168 | 1097 | 1225 |
| MEDIAN | 58 | 32 | 26 | 30 | 34 | 33 | 63 | 53 | 51 |
| MAX | 1553 | 700 | 465 | 331 | 952 | 586 | 1107 | 729 | 710 |

Site codes: S1 - San Ignacio Lagoon; UP = Unimak Pass; OR = Oregon Coast; PL = Pt. Loma (San Diego) ; SC, ' 81 = Southern California Bight in 1981; SC, ' 83 = Southern California Bight in 1963; YP1 = Yankee Pt. , north camp; YP2 = Yankee Pt. , middle camp; YP3 = Yankee Pt. , south camp, interesting that our comparison showed a marked difference between the study of westbound migrants in a year when the fall ice cover was heavy and all others (including data on spring migrants under equal ice cover). The median blow interval was lower for this study, suggestive of rapid movement at the surface.

Table 3-3 shows results for the gray whale. Again, the studies differed in their median blow interval significantly. The radio tracking study' in San Ignacio lagoon, and the observations of northbound mothers and calves at Yankee Pt. were not significantly heterogeneous; the Pt. Loma study was different from all others. This latter difference was probably due to a very much lower representation of intervals in the long dive time classes, while the former may be a function of the large proportion of mothers and calves studied at both locations. Differences in distribution of blow intervals explainable by behavioral differences have been reported for the gray whale in the Chirikov Basin (Wursig et al, 1984b), although we did not have access to these data. Blow intervals were heterogeneous age classes in this latter study as well.

A reasonable interpretation for our results and those published is that there are fine-scale heterogeneities in surfacing behavior based on activity and age of these whales, and some broadscale differences not identified by any one study between phases of the migratory cycle. We decided not to attempt a model of fine-scale behavior since all studies reported that the bowhead whale was very unpredictable in location and type of behavior from year to year and little information was available north of Unimak Pass for the gray whale. Because the model we were developing was intended to be very broad scale, and because there were no data for many phases of the migration, we decided to pool the data from all studies. We understand that the studies conducted are by no means unbiased surveys of all behaviors and all areas. Future versions of the model based on additional data collected during various phases of migration might account for the differences observed between westbound migration and summering, and eastbound migration of the bowhead whale. Further work in the Bering Sea would be necessary to create such a model for the gray whale.

Sequencing of blow intervals was also an important factor in modeling diving and surfacing behavior. Initially, we used a time-series approach to modeling the sequences but found it was not appropriate to generating long sequences of modeled behaviors, although the results of this analysis suggested that the current dive time might be predicted very well by the previous dive or previous two dives (HMRI, 1985). We determined how much knowledge of previous blow intervals contributed to the prediction of the current blow internal using an information theory approach outlined in detail in Chatfield and Lemon (1970). For both the gray and the bowhead whale the average uncertainty changed with knowledge of previous dives. The difference in H (average amount of information) between the current and previous dive for the gray whale was 0.24, whereas it was on the order of 0.01

Table 3-3. Pairwise comparisons between studies using distributiona of blow intervals for the bowhead whale, using a multiple comparison test based on the Kruskal-Wallis *ranked sum test;* whole table significant ($H = 335.24$, $df = 8$, $p < .01$). Each cell in the table gives the difference between mean ranks and indicates significance (*) . Sample size, and median and maximum blow interval are given for each study.

| PHASE<br>SITE | EASTBOUND<br>C. LISBURNE | EASTBOUND<br>PT. BARROW | WESTBOUND<br>AK BEAUFORT | SUMMER<br>CAN . BEAUFORT , ' 82 | SUMMER<br>CAN . BEAUFORT , ' 83 |
|---|---|---|---|---|---|
| C. LISBURNE | --- | | | | |
| PT. BARROW | 217.79 | --- | | | |
| AK BEAUFORT | * 263.92 | * 481.71 | --- | | |
| CAN. BEAUFORT,'82 | 58.28 | 159.51 | * 322.20 | --- | |
| CAN. BEAUFORT,'83 | 163.69 | 54.10 | * 427,62 | * 105.41 | --- |
| N | 254 | 145 | 909 | 383 | 454 |
| MEDIAN | 15 | 19 | 12 | 15 | 18.5 |
| MAXIMUM | 1201 | 534 | 1293 | 1859 | 773 |

for second and third previous dives. For the bowhead the values were 0.26 for the first previous, and 0.44 for the second previous; the value could not be computed for the third previous dive. This means that a first-order Markov transition matrix could be used to model the sequences of behaviors for the gray whale quite readily, whereas a higher order model might have explained the behavior of the bowhead whale better. Unfortunately, data in the longer dive-time classes were not sufficient to produce such a model,

To develop the Markov transition matrices used to describe bowhead and gray whale diving behavior, the original sequences of surfacing intervals derived from the ensemble of all data sources were broken into bins or categories. Each category was a range of dive intervals, which was chosen to be as broad as possible while still representing the modal frequency distribution of observed blow intervals.

Figures 3-1 and 3-2 show the categorized frequency distributions for bowhead and gray whale surfacing/diving behaviors. In each case, five bins were identified. For bowhead whales (Figure 3-l), the bins are for blow intervals of 1-9, 10-19, 20-34, 35-349, and 350+ seconds. As the figure shows, over 70% of the behaviors fall into bins one and two (i.e., below 20 seconds), as might be expected from the 7:1 ratio of blows per surfacing to dives for this species (Table 3-4). The mean dive time was about 12 minutes (Figure 3-l), although the mean interval between surfacings, including rolls and blows between dives, is only 53 seconds. For gray whales (Figure 3-2), the bins cover dives of 1-24, 25-64, 65-124, 125-299, and 300+ seconds. Here about 65% of the observations fall into the first two bins (i.e., below 65 seconds) . The mean dive duration for the gray whale is only about 3 minutes, due to the low number of very long dives in the distribution and a strong second mode in the distribution at 125 seconds. Including short rolls between longer dives, the mean interval between surfacings is about 2 minutes (Table 3-4). The bowhead whale thus dives and surfaces for relatively long periods relative to the gray whale. This means that if a bowhead whale encounters oil at all, the exposure will be greater than for the gray whale (assuming no change in normal behavior), although its chances of encountering oil are smaller.

First and second order transition matrices were calculated for both species using all available data to maximize sample size (see discussion on heterogeneity above). First order matrices represent the probability of the current dive falling into a particular category given the category of the previous dive; second-order matrices represent the probability of the current dive category given the categories of the previous two dives. While the second-order matrix might provide a better estimate of the current dive in the case of the bowhead whale, it also required more data than were available; for consistency we used a first order model for both species.

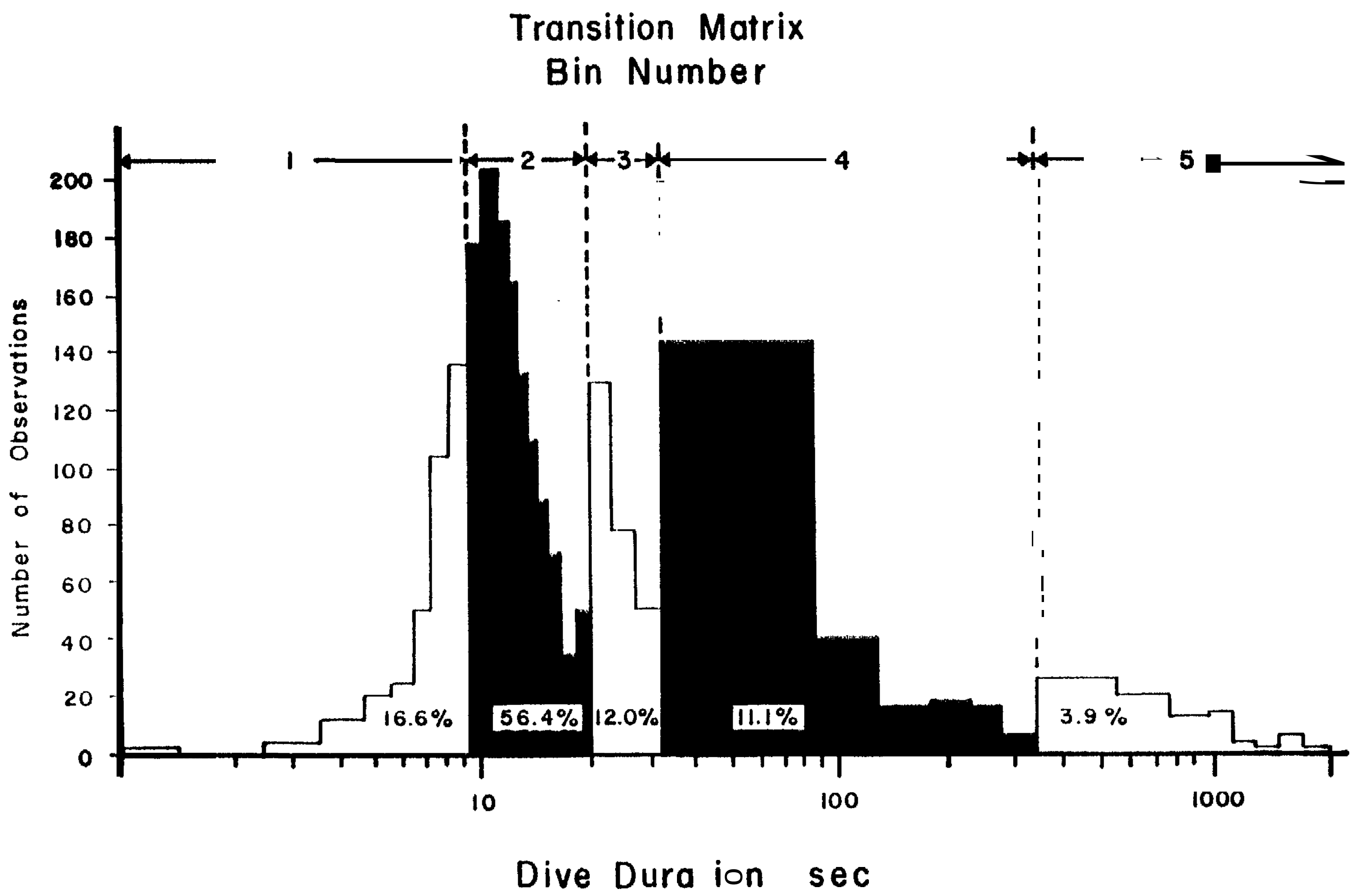



Figure 3- Frequency distribution of dive times for bowhead whales.

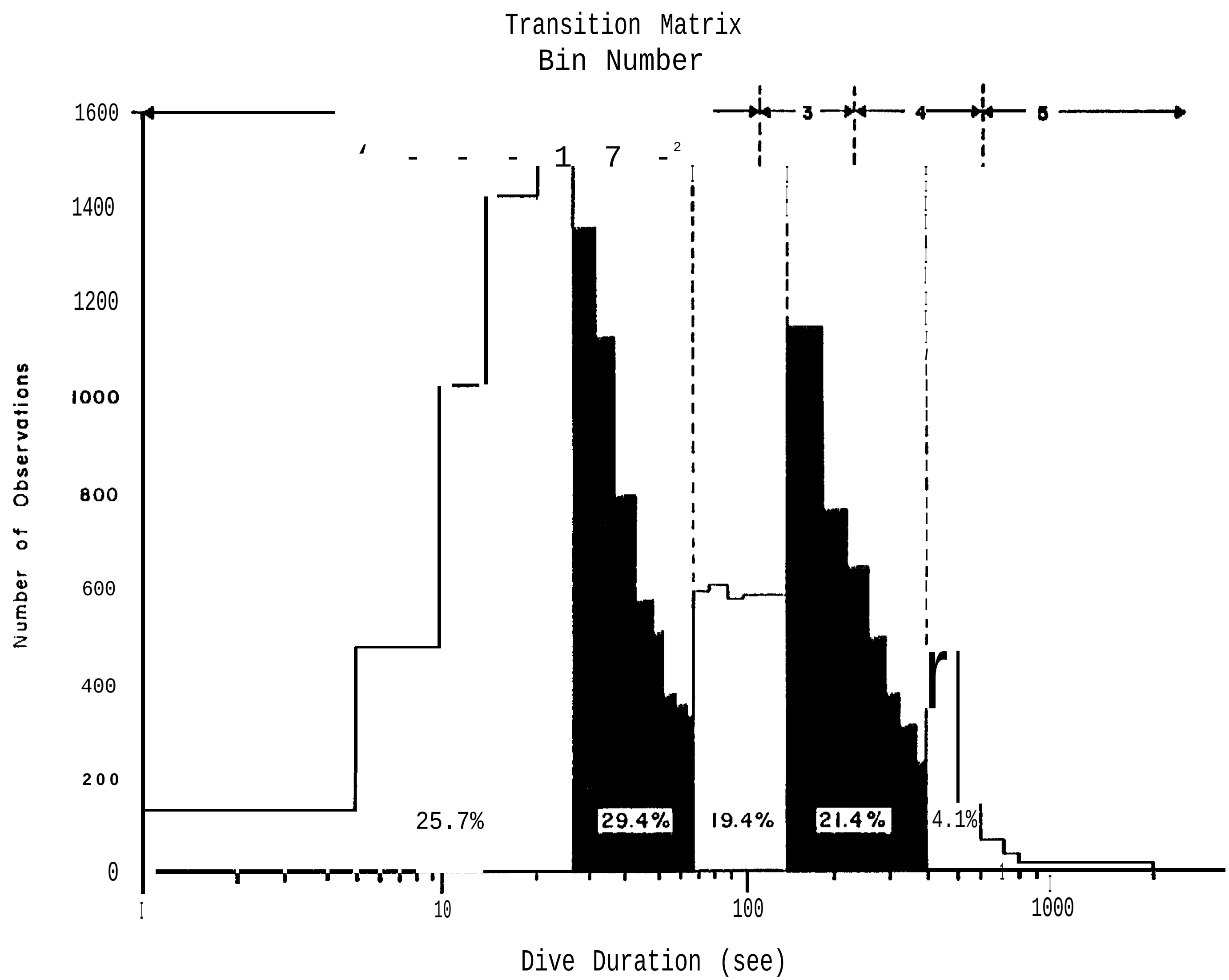



Figure 3-2. Frequency distribution of dive times for gray whales.

Table 3-4. Mean dive times, number of blows/surfacing, median blow internals and mean intervals between surfacings for gray and bowhead whales.

| | Mean Dive Time (see) | Mean Blows/ Surfacing | Median Blow Interval (see) | Mean Interval Between Surfacings (see) |
|---|---|---|---|---|
| Gray Whale | 186 ± 101 (SD) | 2 ± 1 (SD) | 20 | 53 |
| Bowhead Whale | 724 ± 549 (SD) | 7 ± 3 (SD) | 15 | 94 |

In order to determine a number of surfacings within a given period of time, the diving-surfacing model is run as follows. First, a random number is selected between zero and one. This number is used to identify the category from which the first dive will be drawn. For example, assume that a bowhead whale sequence is to be generated, and the random number drawn is 0.782. From Figure 3-1, we select the length of blow internal at which 78.2% of the intervals are as small or smaller; in this case we select a point which falls within bin 3, 20-34 seconds. A second number between O-1 is drawn, and used in a similar fashion to assign a specific duration within the range of bin 3. The mean value of the appropriate sub-bin (or histogram step, Figure 3-1) is used as the actual value of the initial dive. This dive duration is subtracted from the time period of interest and the number of surfacings is set to one. Now two more random numbers are generated, and the Markov transition matrix is entered to determine the bin for the subsequent dive given the bin of the first dive and the first of these random numbers. The actual duration of the second dive is then assigned using the second random number to determine which sub-bin the dive should come from. The dive duration is subtracted from the remaining time in the period of interest, and the number of surfacings is incremented by one. This process is carried out for as long as the modeled whale is in oil.

To test the behavior of this model relative to the observed distributions, we generated sequences of 2000 dives and compared the distributions of intervals in these sequences with the original distribution using the Kruskal-Wallis rank sum test. Differences between 10 simulations and the original distribution were not significant by this measure ($H = 19.01$; $df = 9$; $p > .01$).

## 4. Oil Spill Model

An oil spill trajectory and fates model is used to generate time series of surface area coverage as input to the migratory bowhead and gray whale models. This report section documents the algorithms and methodologies underlying the trajectory model. The model is based on a comprehensive three dimensional oil spill fates simulator originally developed for the Department of Energy and the Bureau of Land Management for oil spill - fishery impact assessment (Cornillon et al, 1979a, b; Reed, 1980; Anderson and Spaulding, 1981; Reed et al, 1985; Spaulding et al, 1982a, b, 1985).

### 4.1 Oil Spill Drift

Surface oil is represented in the model by a series of oil patches, or spinets. Spinets can assume any shape, but in the present study they are constrained to circles, facilitating spreading as well as whale interaction computations. Although the spinets themselves are circular, the use of a number of spinets allows the model to estimate spatial distributions which are non-circular; the more spinets one uses in a simulation, the better the model can resolve irregular shapes and patterns, as well as oil "patchiness".

The oil spill trajectory model computes transport based on wind, wave, and ocean current (hydrodynamic) submodels. Wind and wave effects have been combined together for the work described here, such that the movement or drift of oil in open water can be expressed by the following vector relationship:

$$U_{oil} = U_{wind} + U_{tide} + U_{residual} \tag{1}$$

where

$U_{oil}$ - oil drift vector (m/s)

$U_{wind}$ - wind induced surface oil slick current vector, including Stokes drift (m/s)

$U_{tide}$ - tidal current vector (m/s)

$U_{residual}$ - residual current vector (m/s)

The wind and tidally induced flows typically vary on time scales on the order of hours. The residual flows on the other hand are quasi-permanent currents including tidally induced residual currents, density driven currents, river induced flows, and long term wind driven flows. This residual current field changes on a much longer time scale, typically month to month, in response to changes in the seasonal patterns of climatological forcing.

Following, well known empirical formulations (e.g., Stolzenbach et al, 1977), the magnitude of the wind driven contribution to slick drift is parameterized as 3.5% of the wind speed. The direction of the wind-induced oil drift current is modified by a deflection angle, based on the recent work of Samuels et al (1982) for Alaskan coastal waters, taking into account the influence of wind speed on deflection:

$$e = 25° \exp(-10^{-8}U^3/\nu g) \qquad (2)$$

where

$\theta$ - deflection angle (0), [clockwise from the wind vector in the northern hemisphere]
u - wind speed at 10 m above sea surface (m/s)
$\nu$ - kinematic viscosity of seawater (centistokes, $cm^2$/see)
g - acceleration of gravity ($m/sec^2$)

At low wind speeds (<5 m/see) the deflection is about 250 to the right of the wind in the northern hemisphere, but decreases towards 0° as the wind speed increases.

When oil is located beneath ice the movement is considerably more complicated (Sayed and Abdelmour, 1982; Uzuner et al, 1979; Cox and Schultz, 1981a,b). When the relative speed between ice and the underlying water is below a critical threshold value, the oil is effectively trapped by the ice roughness end hence moves with the ice. If the ice is stationary (i.e., fast ice) the spill of course remains fixed. This threshold or critical speed is estimated from Cox and Schultz (1981a,b) and Cox et al (1981) by the empirical expression

$$U_{th} = 305.79/(88.68-\mu) \qquad (3)$$

where

$U_{th}$ - threshold current speed (cm/s)
$\mu$ - viscosity of oil (poise, gm/cm-see)

As the viscosity increases, due to temperature decrease or emulsification, the threshold value increases dramatically. Once the critical value is exceeded, the oil begins to move according to the relationship (Cox et al, 1981)

$$'oil = U_{water} \quad (1-( K/0.115F + 1.105)^{\frac{1}{2}} ) \qquad (4)$$

where

$U_{oil}$ - oil drift speed (cm/s)
$U_{water}$ - water speed beneath the ice (cm/s)
K - roughness amplification factor
(1 for smooth ice, greater than 1 for rough ice)

The densimetric Froude number, F, is computed as

$$F = U_{water}/(g(\rho_w - \rho_o)\delta/\rho_w)^{1/2}$$

where

$g$ - gravitational acceleration (cm/sec$^2$)
$\rho_w$ - density of water (gm/cm$^3$)
$\rho_o$ - density of oil (gm/cm$^3$)
$\delta$ - thickness of the oil slick (cm)

Following the data of Cox et al (1981) we have assumed that K increases quadratically from 1 to 2.8 as the ice roughness goes from 0.1 to 1 cm. If the ice is smoother than 0.1 cm or rougher than 1.0 cm, K is held constant at 1 and 2.8, respectively. Since ice roughness is parameterized as 20% of ice thickness (NORCOR, 1975), we are generally operating at the latter limit.

The expression for $U_{water}$ includes only the tide end permanent or residual currents, the wind driven surface velocities being assumed as zero below the ice. The oil under ice is then advected using Eq. (4), provided the threshold velocity has been exceeded.

For spills in broken ice fields our knowledge of the dynamics of oil-ice interaction is extremely sketchy, particularly in terms of quantitative definitions (Thomas, 1983a; Stringer, 1980; Stringer and Weller, 1980). Using observations that oil incorporated in a drifting field of broken ice responds similarly to the ice (Thomas, 1983b; Allen, 1983; Coon and Pritchard, 1979; Lewis, 1976; Reimer, 1981) we use a simple ice drift model to predict the motion of the oil.

Assuming that the ice is in free drift, steady state motion, that the ice thickness is on the order of one meter, and that the water column depth is approximately 40 m, we can approximate the wind driven motion of the ice based on a numerical ice drift model for the Bering Sea (Overland et al, 1984) as:

$$u''_{ice} = 0.033 \text{ u Cos } (35^o) \qquad (5)$$

where

$u''_{ice}$ - ice drift velocity (m/s)
U - wind speed at 10 m above the sea surface (m/s)

The deflection angle between the wind and ice induced movement is 35° to the right of the wind (Overland et al, 1984). Although Overland reports deflection angle variation with both water depth and wind speed, the variability is small, and is neglected here. This approach only applies for the case when the ice is assumed to be in free drift. When broken ice approaches the shoreline, fast ice, or pack ice, this methodology is not strictly applicable, and simulated trajectories nearshore in ice-covered waters will therefore be unreliable.

In the Chukchi and Beaufort Seas, mean ice motion at greater than 90% ice cover is dictated by motion of the pack ice as a whole more than by local wind forcing. The mean motion of the ice pack north of 70° N, south of 74° N, west of 141° W (Demarcation Point), and east of 180° W (Wrangel Island), appears to be consistently toward the WNW at about 2 km/day with a random component of about the same order of magnitude (Murphy et al, 1983; Colony, 1979; Colony and Thorndike, 1984). Although some ice occasionally drifts through the Bering Strait into the northern Bering Sea, this is not the norm (Colony and Thorndike, 1985). Following the observed behavior of sea ice buoys in the southern Chukchi Sea, the motion of pack ice south of 70° N and north of 68° N (circa Pt. Hope) will be modeled as being at 2 km/day towards the northwest, with a random component of 2 km/day. During heavy ice years, it is quite possible that oil spilled under ice will drift with the ice pack and become incorporated into the transpolar drift stream. In such cases, the interaction simulation ceases when the oil is transported farther west than 180° W, or farther north than 740 N.

## 4.2 Spreading

Oil spreading in open water is calculated using the gravity-viscous formulation of Fay (1969, 1971), Fay and Hoult (1971), and Hoult (1972). This is the second of three regimes accounted for by these authors, and is the basis for the “thick slick” equation used by Mackay et al (1980). This approach is used in open water and up *to* 30% ice coverage.

For oil spills under pack or fast ice it has been observed that the oil is trapped by the under-ice roughness elements and that the oil will not move unless the currents exceed a critical threshold. The trapping volume for perfectly smooth ice is 8,000 $m^3/km^2$ and progresses from 10,000 to 60,000 $m^3/km^2$ as the ice roughness increases (Kovacs, 1977, 1979; Kovacs et al, 1981; Thomas, 1983a; Cox et al, 1981). In multiyear ice trapping volumes up to 293,000 $m^3/km^2$ are possible due to ridging (Kovacs, 1977). Following the work of Thomas (1983a), where the trapping areas have been assumed as a sinusoidal function of the ice roughness amplitude and the roughness parameterized as 20% of the ice thickness (NORCOR, 1977) the oil storage volume per square kilometer can be expressed by

$$V = 0.0318\ h \times 10^6\ m^3/km^2$$

where

$V$ - veil storage volume per unit area ($m^3/km^2$)
$h$ - ice thickness (m)

If the ice thickness is 0.25 m or less, the storage volume is assumed equal to 8,000 $m^3/km^2$ representing the lower bound for oil storage on a smooth ice surface (Cox et al, 1981).

Oil released under fast or pack ice is assumed to instantaneously occupy that area of the oil storage volume necessary to accommodate the spinet mass. The radius of the spinet is calculated by

$$r = (M/\pi\rho_o V)^{1/2}$$

where

$r$ - radius of spinet (km)
$M$ - mass of spinet (kg)
$\rho_o$ - density of spinet ($kg/m^3$)
$V$ - veil storage volume per unit area ($m^3/km^2$)

Additional spinets released under ice occupy adjacent storage volumes in direct proportion to their mass and the available storage areas.

The literature is extremely sketchy regarding the behavior of oil spreading in broken ice fields. Laboratory experiments by Free et al (1981) show that low viscosity oils like diesel fuel can penetrate ice fields, with up to 90% coverage; however, the higher viscosity crude oils were unable to flow through similar ice infested waters. Based on the limited observations that ice tends to herd oil we have assumed that the oil thickness is increased in direct proportion to the percent of the surface area covered with ice. The radius of the spinets has been assumed to be given by the Fay-Hoult spreading algorithm. We have assumed that for ice coverage below 30%, open water conditions prevail while ice concentrations above 90% correspond to complete ice coverage (LaBelle et al, 1983). This upper bound assumption has been made recognizing the fact that when ice coverage exceeds 90%, the broken ice field behaves essentially like pack ice and also to prevent the oil thickness from going to infinity in the simple spreading, actually herding, algorithm employed here.

## 4.3 Evaporation

The evaporation of hydrocarbons from each spinet is computed according to the model reported by Payne et al (1984), which uses the rate calculation of Mackay et al (1980). For an oil characterized by a series of boiling point fractions, the evaporation rate of the $i^{th}$ fraction is given by:

$$dM_i/dt = K_i P_i A f_i/RT$$

where

$P_i$ = vapor pressure of fraction i (atm)
A = slick area ($m^2$)
$f_i$ = molar fraction of i remaining in slick
R = gas constant ($8.206 \times 10^{-5}$ atm-$m^3$/g-mole-°K)
T = temperature (°K)

The mass transfer coefficient Ki is computed by

$$K_i = 0.029 \; U^{0.78} D^{-0.11} \sqrt{(MW_i + 29)/MW_i}$$

in which

u = wind speed (m/hr)
D = slick diameter (m)
$MW_i$ = molecular weight of fraction i

## 4.4 Entrainment

The entrainment/dispersion of oil into the water column from the surface slick is based on Spaulding et al (1982c) in which the dispersion rate F is computed as

$$F = 0.1(U^2/U_o^2) \; e^{-rt}$$

where

U. = reference wind speed (8.5 m/see)
r = constant (0.5 per day)
t = time (days)

## 4.5 Circulation Dynamics

The tidal and residual or net circulation in the Bering, Chukchi, and Beaufort Seas has been calculated using ASA's three dimensional hydrodynamic model. A brief description of the model is presented below with a more detailed development given in Owen (1980), Isaji and Spaulding (1984), and Isaji et al (1982).

The three dimensional conservation equations for water mess, density, and momentum with the Boussinesq and hydrostatic assumptions invoked form the basis for the model. These equations are solved subject to the following boundary conditions. (1) At land boundaries the normal component of velocity is set to zero. (2) At the open boundaries the sea surface elevation is specified as a series of sine or cosine waves each with its own amplitude and phase or appropriate gradients of the local surface elevation. (3) At the sea surface the applied stress due to the wind is matched to the local stress in the water column and the kinematic boundary condition is satisfied. (4) At the sea floor a quadratic stress law, based on the local bottom velocity, is used to represent frictional dissipation and a friction coefficient parameterizes the loss rate.

Operating in the two dimensional vertically averaged mode the model was applied to the study area to determine the response to the $M_2$ (semi-diurnal) and $K_1$ (diurnal) tides. These tides were selected because they represent the two tidal frequencies with most of the energy for the study area and have been shown by Liu and Leendertse (1983) to adequately describe the tidal dynamics. For the applications reported here, the model employed a 12 nautical mile square grid on a spherical coordinate sys tern. Bathymetric data describing the area was derived from the National Ocean Survey (NOS) hydrographic data base. Boundary condition data for the surface elevation, in terms of the amplitude and phase of the $M_2$ and $K_1$ tides, was derived from Schwiderski's (1981) deep ocean tidal model and from data collected by Mofjeld (1984).

## 4.6 Wind Fields

An accurate representation of marine surface winds is an important element of oil spill trajectory analyses. For analysis of specific oil spill trajectories, appropriate deterministic wind field data are necessary. The land station Surface Airways Observations (National Climatic Center's TDF-3280 format) obtained and processed for the oil spill simulations reported here are listed in Table 4-1. By selecting a year and monthly start date at random, a 25 year record can yield 750 (25 annual records x 30 daily start points per month) different real wind scenarios beginning in any given month. By combining months into seasons, the number of available trajectories can be further increased. To account for differences between mean land and sea climatologies, amplitude and deflection angle corrections based on Brewer et al (1977) are applied as a function of spill location. This methodology has the advantages of being computationally and conceptually simple, and produces historical wind sequences which are real: each scenario has actually occurred. In addition, the approach accounts for the persistence associated with weather patterns and storm tracks, while agreeing with observed wind speed and direction probability distributions in long term simulation tests.

Table 4-1. Location of National Climatic Center wind station records used for oil spill trajectory simulations.

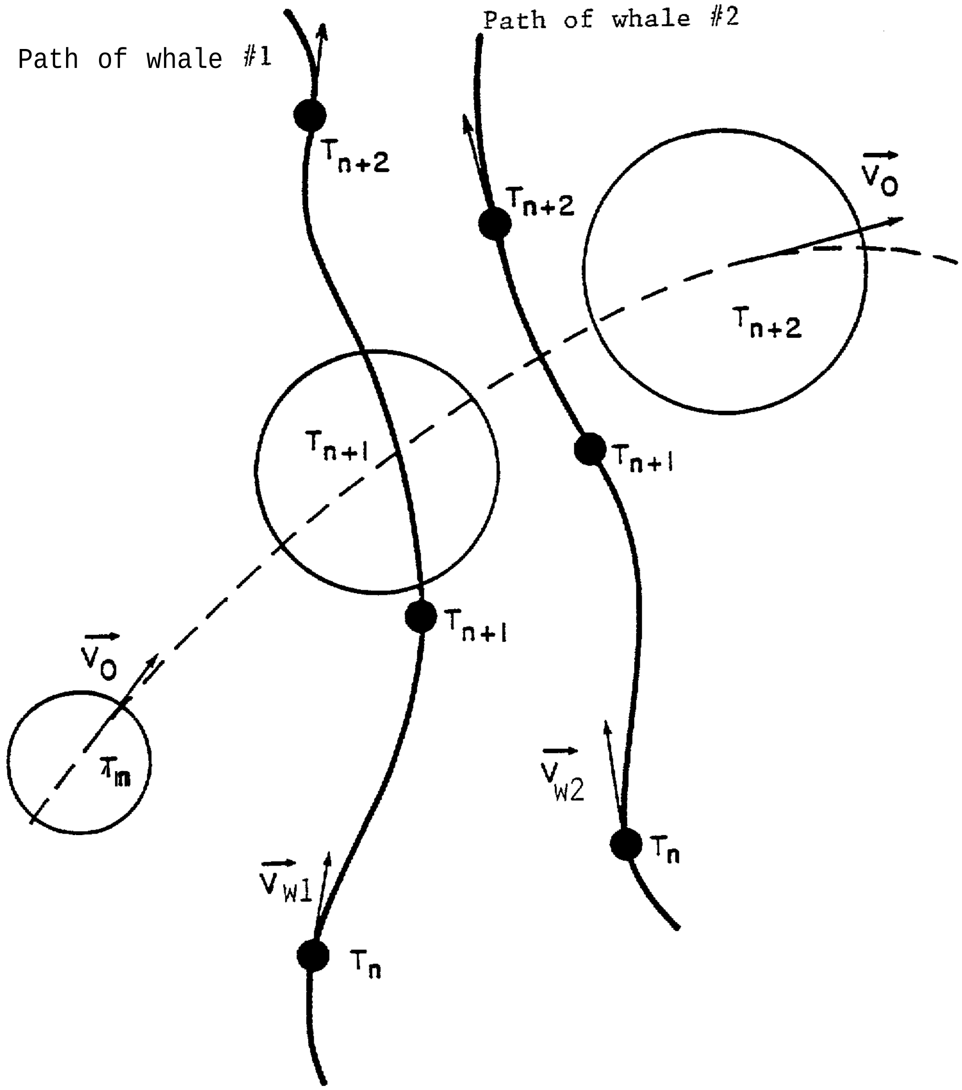
| Station Name | Lat. N | Long. W | Years Recorded |
|---|---|---|---|
| Barrow | 71° 18′ | 156° 47′ | 49-76 |
| Northeast Cape | 63° 19′ | 168° 56′ | 53-68 |
| St. Paul Island | 57° 09′ | 170° 13′ | 55-81 |

## 5. Migrating Whale - Gil Spill Model Linkages

The presence or absence of whales is assumed to have no effect on the trajectory or spreading of spilled oil; the oil spill model is therefore run independently and used to generate spill data (spill size and location time series). The oil spill model output is then input to the migration model. As a migration simulation proceeds, the position of each whale point relative to oil is continuously monitored. Each time a whale point trajectory intersects an oil spinet, the cumulative time the whale spends in the oiled area is calculated. Migration model output consists of the total time each whale point was within the bounds of an oiled area.

Since whale points and oil spinets are moving simultaneously, intersections may occur which fall between time steps and consequently would not be recorded by simply comparing whale and oil locations at the end of each time step. This situation is exemplified in Figure 5-1. The whale on the left (#1) appears to encounter the oil spinet, whereas the whale on the right (#2) appears to avoid it entirely. However, while whale #1 is swimming from position n+1 to n+2 (towards the top of the page), the spinet is processing from n+1 to n+2 (towards the right), and whale #1 will therefore encounter only the trailing edge of the slick. In addition, whale #1 is swimming faster than #2 during the time interval from n+1 to n+2, because a larger distance is covered in the same amount of time. Meanwhile, whale #2, on the right, moves slowly ahead into the path of the oncoming oil slick, and spends considerably more time in oiled water than #1. The concept of relative velocity is therefore used to determine if an intersection of a whale's path with the oil spill trajectory has occurred during the time step. The velocity and position of each whale point are re-calculated relative to the velocity and position of each oil spinet (Figure 5-2). In other words, the process is calculated from the viewpoint of an observer translating with the center of the oil slick. If the line describing the relative movement of a point intersects the circumference of an oil spinet, the time the point spends within the oiled area is calculated. This process is repeated for the life of the oil spill, and the time spent in oil is summed for each whale point. Migration model output then consists of the total time each whale point has been in oil covered water.

An auxiliary computer program is utilized to convert the time spent in oiled water to a number of interactions of the whale points with oil. An interaction is defined as a surfacing of the whale point while in oil-covered water. A first-order transition matrix described in Section 3 is used to describe the probability of a whale point's dive duration falling within a certain time range, given the length of the previous dive. The length of this dive is subtracted from the whale point's total under-oil time and the number of surfacings of the point in oil is incremented by one. This process is repeated until all the under-oil time has been reduced to diving/surfacing sequences for each whale point.




● - location of whales at subsequent timesteps, $T_n$, $T_{n+1}$, $T_{n+2}$

○ - outline and location of oil spinet at subsequent timesteps

$\vec{V}$ - instantaneous velocities of whales and oil spinets

Figure 5-1. Positions of an oil slick and two migrating whales at the end of three sequential timesteps. Contrary to first appearance , whale #2 will spend more time in oil-covered water.

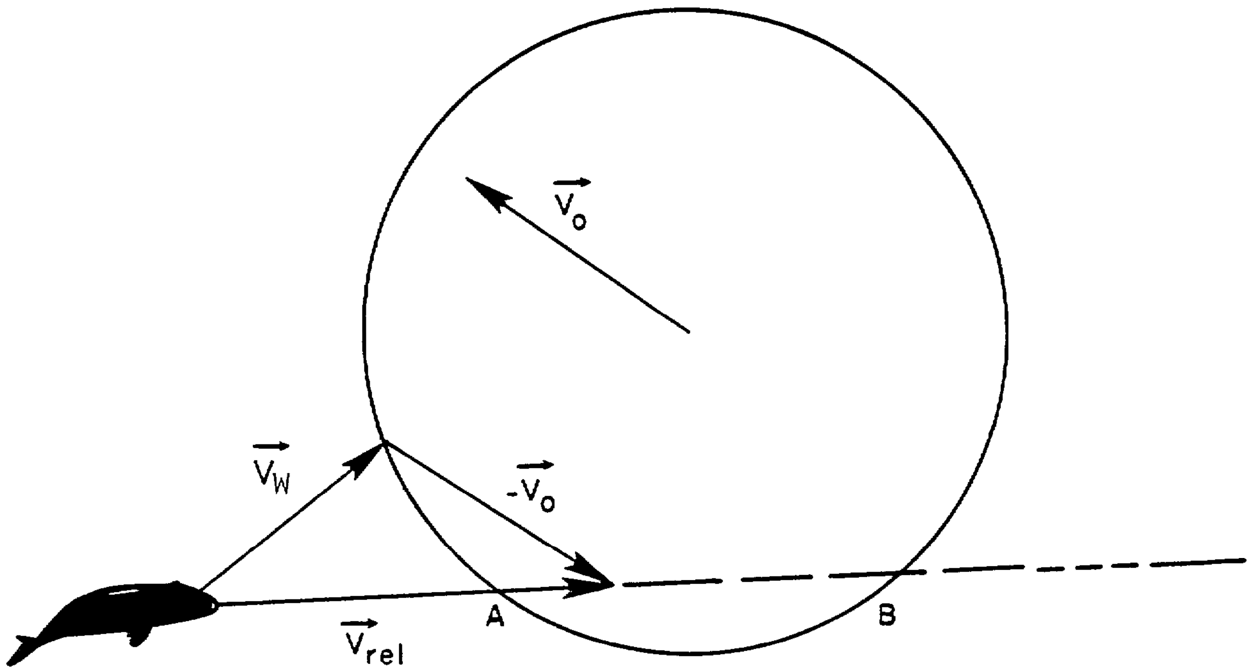



Figure 5-2. Relative velocity, $\vec{V}_{rel}$, of a whale with respect to an oil spinet. $\vec{V}_o$ is the velocity of the oil spinet, and $\vec{V}W$ is the velocity of the whale relative to a fixed reference frame. AB is the chord of intersection, unless either $\vec{V}_w$ or $\vec{V}_o$ changes before the whale has passed point B, in which case the simulated interaction becomes more complex.

## 6. Model System Sensitivity Studies

Four model components directly affect the variability of calculated durations and numbers of whale-oil spill interactions for a given oil spill simulation. These are:

(1) the number of discrete points used to define the dynamic distribution of whales in physical space;

(2) the variability introduced by the random components of the whale migration models;

(3) the timestep used to simulate whale movements relative to moving oil slicks;

(4) the stochastic variability of the dive time model.

Each of these parameters or components has been subjected to sensitivity analysis to determine its relative importance to model system output.

The sensitivities of model output to the number of points used to represent a population and the stochastic components of individual whale point velocities are subject to variation with geographical location and season. This is because both population density and mean migration speed change in space and time, as discussed in Section 2. When population densities are small or migration velocities are large, estimates of whale - oil spill encounters will be more sensitive to numbers of points and velocity variability. Sensitivity studies for these parameters have therefore been performed for all planning areas with the exception of St. George Basin. This area has been exempted because only gray whales encountered oil, and only for spills released directly in Unimak Pass. This spill location is very close to the southern boundary of the gray whale migration model, so that encounter estimates are governed primarily by boundary conditions placed on that model (i.e., oil spill release times relative to peaks in the distribution of gray whales entering Unimak Pass from the south).

Model sensitivity to the number of discrete points used to represent the population was evaluated by selecting a specific oil spill scenario for each species, and performing 10 simulations of whale-oil spill interactions using 200, 500, 1000, and 2000 points to specify the population distributions. Table 6-1 summarizes results for the sensitivity tests of numbers of points and stochastic variability in the migration models. In general, increasing the number of points causes the mean time-in-oil to stabilize, defining a "true" mean value. When only 200 points are used to simulate the population distributions, the mean value of the total time in oil is within approximately 13% of the value at 2000 points for each species. At 500 points, the estimate of the mean is within a few percent of that at 2000 points. Also, as the number of points increases, the model variability due to stochastic changes in individual point

Table 6-1. Summary of sensitivity studies of number of representative whale points used in simulations and stochastic variability in individual migration velocities. Ten replicate simulations were performed in each location, for each number of points.

| Species | Number of whale points | Mean number of whale hours in oil ($\bar{X}$) | Standard deviation about the mean (on-l) | ʻn- 1/$\bar{X}$ |
|---|---|---|---|---|
| | | NAVARIN BASIN | | |
| Bowhead | 200 | 491 | 135 | 0.27 |
| | 500 | 544 | 64 | 0.18 |
| | 1000 | 511 | 90 | 0.18 |
| | 2000 | 553 | 66 | 0.12 |
| Gray | 200 | 102 | 46 | 0.45 |
| | 500 | 93 | 24 | 0.26 |
| | 1000 | 95 | 20 | 0.21 |
| | 2000 | 95 | 11 | 0.12 |
| | | BEAUFORT-CHUKCHI | | |
| Bowhead | 500 | 166 | 28 | 0.17 |
| | 2000 | 178 | 13 | 0.07 |
| Gray | 500 | 109 | 37 | 0.34 |
| | 2000 | 107 | 24 | 0.22 |

trajectories from one run to the next, $\sigma_{n-1}$, would be expected to decrease. At more than 500 points, however, it can be seen (Table 6-1) that the standard deviation does not decrease consistently. This suggests that the variability becomes dominated by stochastic processes intrinsic to the migration model (i.e., the random component of individual migration velocities, and the stochastic selection of migration paths at branch points).

The sensitivity of the model estimates of total time whales spend in oil to the computational timestep was evaluated for two spill scenarios. For both spill scenarios, the gray whale migration, using 2000 points to represent the population, was simulated at 3, 6, 9 and 12 hour timesteps. Timesteps shorter than 3 hours were not investigated, since 3 hours is the minimum resolution in the available wind data used to run the oil spill simulation model. No clear trend emerges as the computational timestep is increased (Table 6-2). The estimated total time in oil can be either greater than or less than the high resolution (3 hour timestep) solution, depending on the details of each scenario. From Figure 5-1, it can be seen that the problem is akin to that of introducing aliasing errors in time series analysis: a sampling rate which is too slow (i.e. , a timestep which is too large) relative to the rate of change in the process being studied does not allow identification of the true characteristics of the process (i.e., gives us an answer upon which we cannot rely). Given that the model estimates at longer timesteps diverge from the higher resolution solution, it is clear that the 3 hour timestep must be retained.

The effect of stochastic variability within the diving-surfacing mode l on computed numbers of whale-oil spill interactions was evaluated by repeated simulations with the dive time model for a single whale migration/oil spill scenario. For each species, each run differs only by the seed number used to initialize the random number generator in the diving-surfacing model. All other aspects of the simulation, including oil spill and individual whale point trajectories, remain constant. Results for each species are given in Table 6-3. The ratio of the standard deviation to the mean is about 3% for the gray whales, and 2% for the bowheads. It is clear that only small run-to-run variations are attributable to the diving-surfacing model, relative to variations attributable to sources described above.

The number of spill scenarios at a given site necessary to represent adequately the effects of year-to-year variability on the probability distribution of whale-oil encounters is another issue which must be resolved for each study area. Studies were performed comparing the summary encounter histograms for N=10, 20, 30, 40, and 50 separate scenarios. The results of these studies (Figures 6-1a,b,c) show that only small changes in the histogram occur for N > 20. Twenty to 30 scenarios, drawn at random from the historical wind record, are clearly enough to avoid biases in the output due to extreme weather scenarios. This appears to be true in all three study

Table 6-2. Summary of model system sensitivity to computational timestep, showing total time individual whale points are within oil slicks for two spill scenarios. To reduce other sources of variability the tests were run with 2000 individual points.

| Model timestep At (hr) | Total time (hrs) individual points are within oil slicks | |
|---|---|---|
| | Spill #1 | Spill # 2 |
| 3 | 390 | 120 |
| 6 | 393 | 90 |
| 9 | 480 | 118 |
| 12 | 413 | 86 |

Table 6-3. Summary of sensitivity studies of the contribution of the diving-surfacing model to variability in the number of whale-oil interactions.

| Species | Number of repeat simulations (N) | Mean number of whale oil encounters ($\bar{X}$) | Sample standard deviation about the mean ($\sigma_{n-1}$) | $\sigma_{n-1}/\bar{X}$ |
|---|---|---|---|---|
| Gray | 20 | 26,100 | 780 | 0.03 |
| Bowhead | 20 | 69,500 | 1180 | 0.02 |

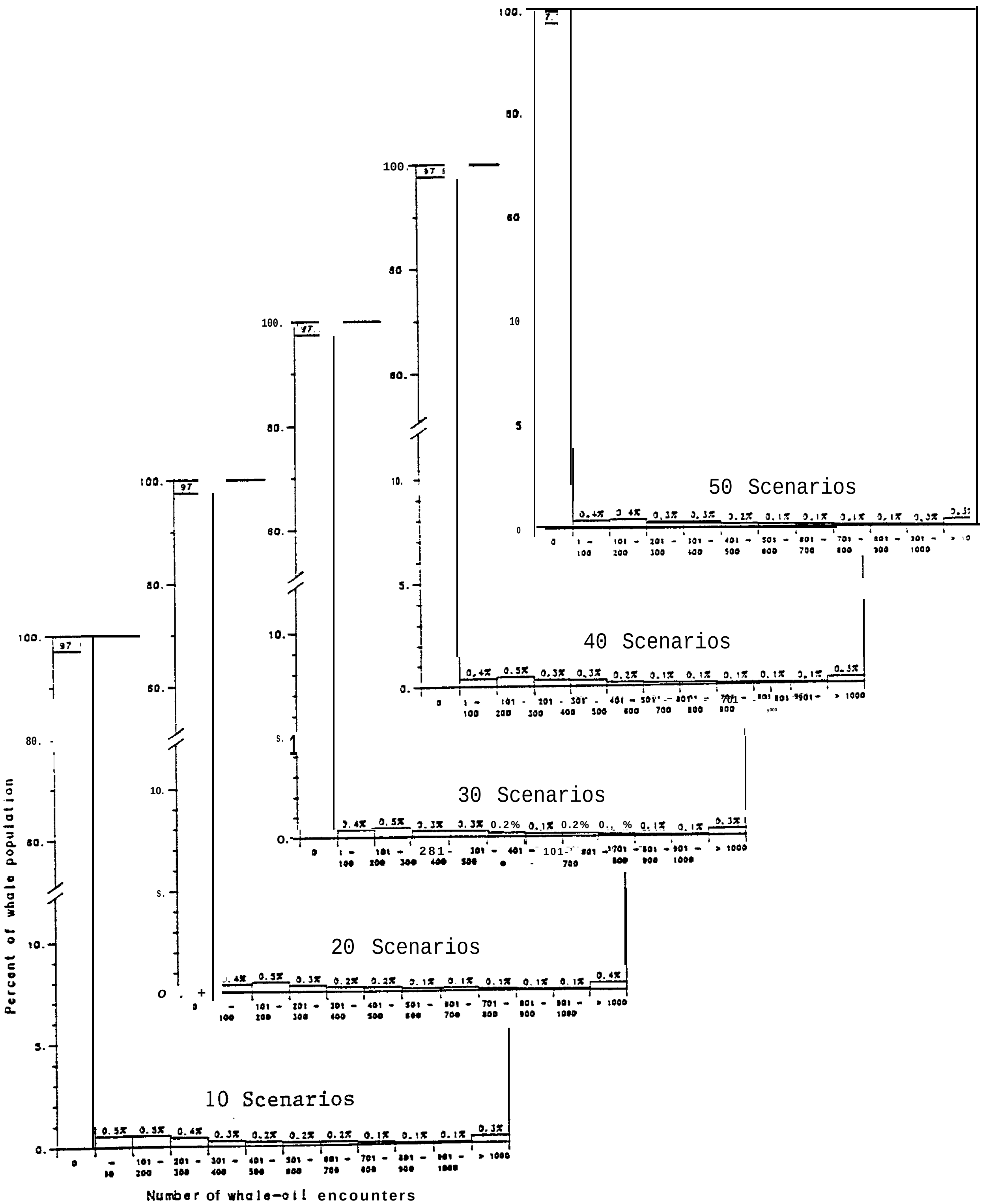



Figure 6-la. Sensitivity of whale - oil spill interaction frequency histograms-to number of different stochastic trajectories at one release site in the Navarin Basin Planning Area.

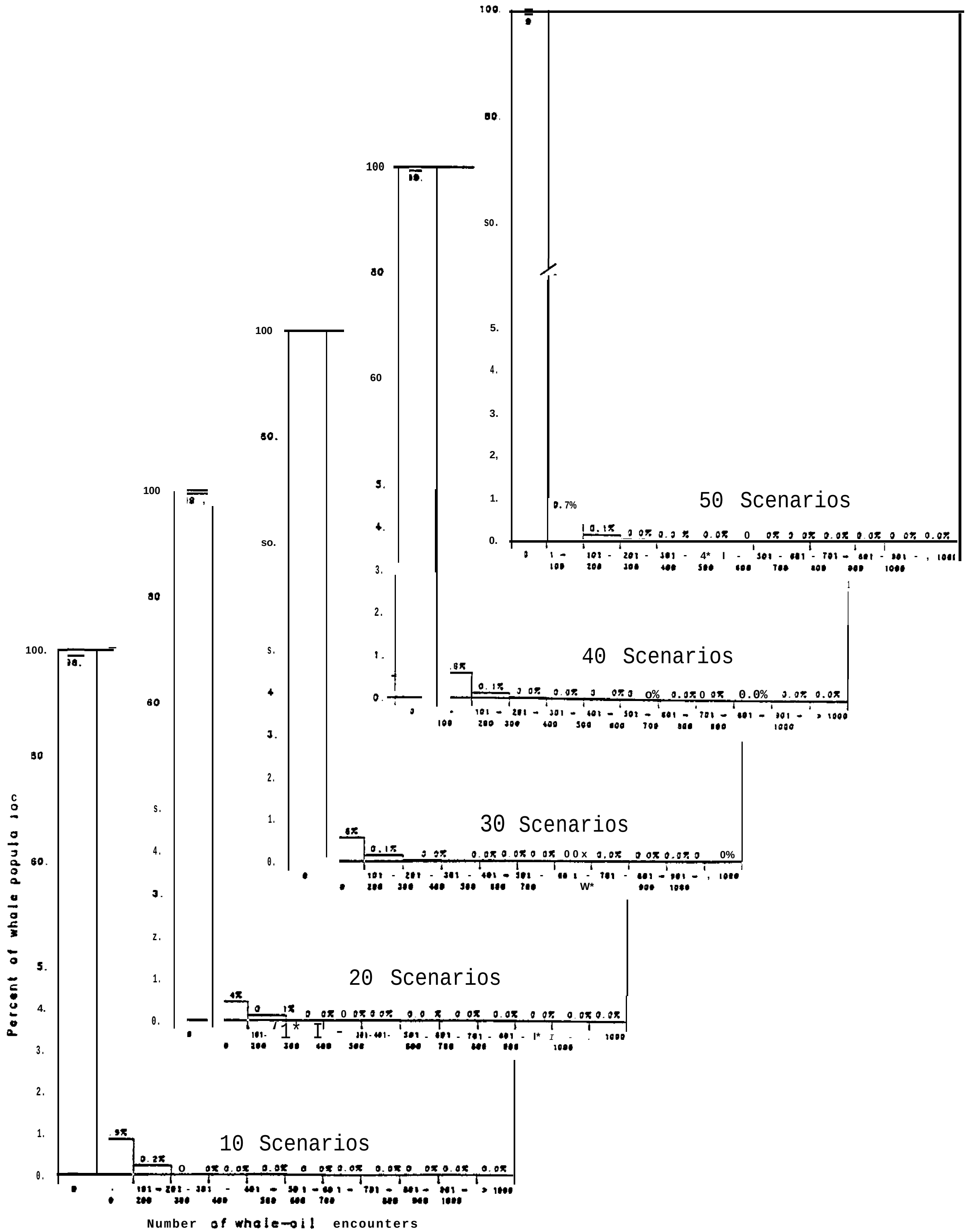



Figure 6-1b. Sensitivity of whale - oil spill interaction frequency histograms to number of different stochastic trajectories at one release site in the Chukchi Planning Area.

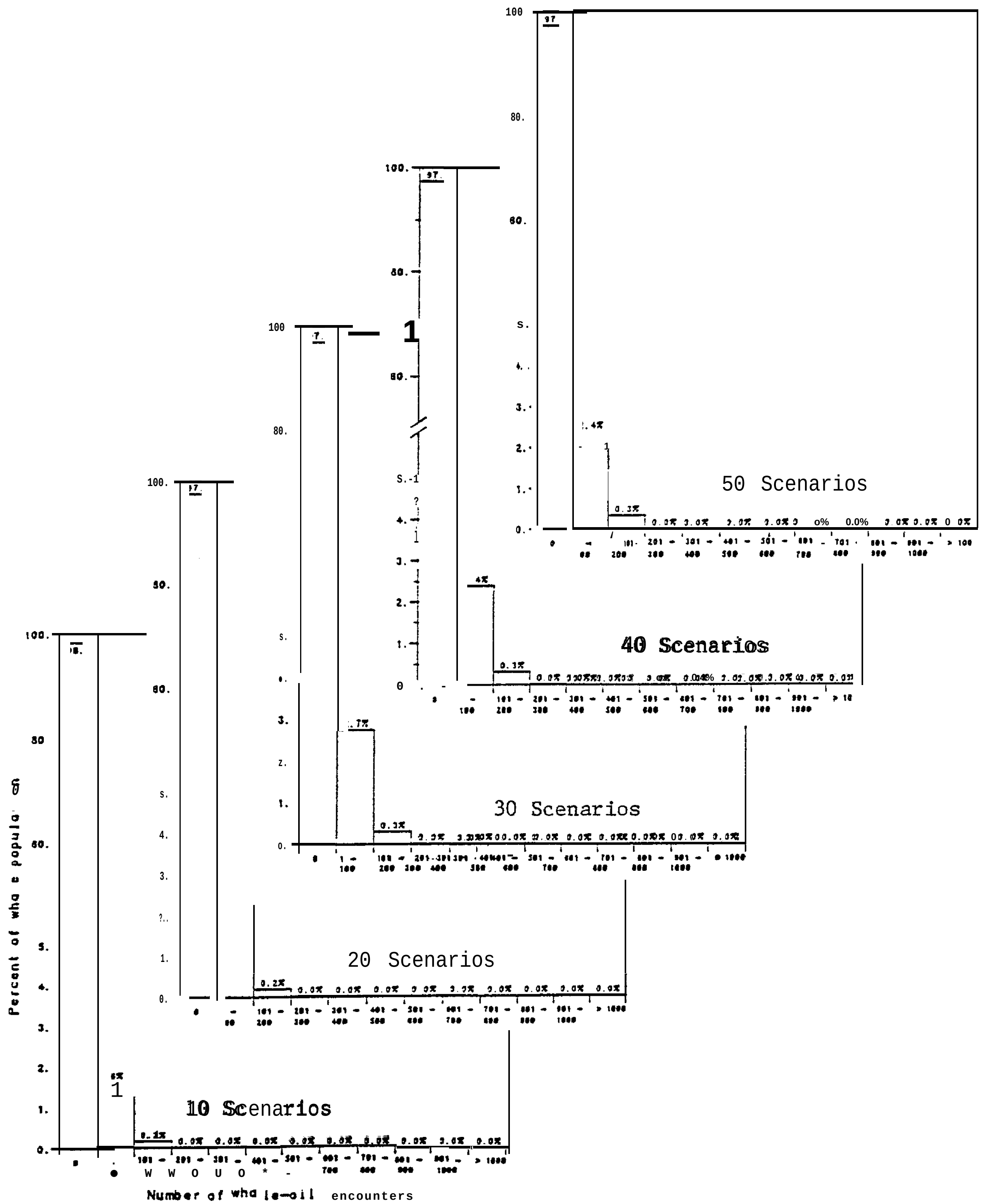



Figure 6-1c. Sensitivity of whale - oil spill interaction frequency histograms to number of different stochastic trajectories at one release site in the Beaufort Planning Area.

areas tested. Again, St. George Basin has not been included since the issue there is one of boundary conditions. Since computational costs are proportional to the number of cases simulated per release site, it was decided to use 25 cases per season per site. This number is also consistent with past MMS/OCSEAP oil spill risk analysis work (e.g., Samuels and Lanfear, 1983).

It is of interest to know whether or not the number of whale-oil interactions associated with a spill can be expected to scale linearly with spill volume and duration. Since whales are not uniformly distributed in space and time, we would not expect such a scaling law to hold for any specific spill scenario, although it might hold in some mean sense. We hypothesize two spill scenarios, each from the same location and subject to the same environmental conditions. Let the spills have volumes $V_1$ and $V_2$, and durations $t_1$ end $t_2$, respectively, such that

$$V_2 = aV_1$$

$$t_2 = bt_1$$

for scalars a, b > 1. If we neglect nonlinearities in the mass removal rate due to evaporation and dispersion, then the potential exposure time, $E_2$, for a whale encountering the larger slick should scale approximately as the ratio of the diameters, $D_2/D_1$. Assuming that surface slicks in both cases will rapidly approach the same asymptotic thickness, then the areas scale as the volumes,

$$A_2 = aA_1,$$

and

$$D_2/D_1 = \sqrt{a}$$

Assuming the population to be homogeneously distributed in the spill area and moving randomly, the potential exposure time for the larger spill, $E_2$, should be further increased by the longer duration, $t_2$. The ratio of the longer to the shorter exposure time, which due to the low variability of the dive time model will be very nearly equal to the ratio of the numbers of whale-oil interactions, is then

$$E_2/E_1 \approx \sqrt{a}\, b$$

To test the hypothesis stated by this equation, we simulated two spills with the following parameters:

$V_1$ = 10,000 bbl
$t_1$ = 15 days
$V_2$ = 100,000 bbl
$t_2$ = 20 days.

Twenty-five weather scenarios were selected, applied to each spill from the same site, and the results averaged (Table 6-4). For this test case, $a = 10$ and $b = 1.33$, so that the expected mean exposure ratio, $E_2/E_1$, should be approximately 4.2. The mean ratio, computed in Table 6-4, is 7.2. Thus the scaling rule given above, although not extremely accurate, appears adequate for order of magnitude estimates.

The assumptions used in arriving at the above scaling law, especially those concerning homogeneity of distribution of whales and randomness in their movements, are not strictly valid. We therefore expect some errors to arise in the estimation methodology outlined here. When extrapolating from very small to very large spills, these errors may become significant, and can only be overcome by application of the full simulation model system.

In summary, the sensitivity studies described above demonstrate that:

(1) as the number of discrete points used to represent the population increases, the mean total exposure time stabilizes;

(2) the variability of the exposure time estimate due to the stochastic components of the migration model exceeds that due to number of discrete points at about 500 points;

(3) a timestep exceeding the 3 hour timestep used to run the oil spill model results in erroneous estimates of whale-oil interactions;

(4) the dive time model contributes only a small fraction of the total variability of the interaction estimates;

(5) 25 scenarios are sufficient to avoid bias in the results due to inter-annual variability;

(6) whale-oil interactions scale approximately with spill size and duration in the average sense, although there is considerable variability from one spill to another, causing the approximation to be unreliable for specific cases;

(7) inter-annual variability in weather scenarios, and therefore the difference between one oil spill trajectory and another, represents the major source of variability in whale-oil spill interaction estimates.

Additionally, the sensitivity analyses show that as the total potential exposure time (i.e., total time whales are within the

Table 6-4. Empirical test of theoretical relationship between spill size and number of whale-oil encounters. One set is 10,000 bbl released over 5 days, the other is 100,000 bbl released over 10 days. Each scenario is simulated for an additional 10 days after last release of oil.

| | Number of Whale - Oil Encounters | | |
|---|---|---|---|
| Spill Scenario | $V_1$ 10,000 bbl | $V_2$ 100,000 bbl | $E_2/E_1$ Interaction Ratio |
| 1 | 0 | 191 | |
| 2 | 882 | 2118 | 2.40 |
| 3 | 1687 | 7566 | 4.48 |
| 4 | 6550 | 19033 | 2.91 |
| 5 | 612 | 6622 | 10.82 |
| 6 | 1138 | 5659 | 4.97 |
| 7 | 4577 | 13365 | 2.92 |
| 8 | 0 | 0 | |
| 9 | 644 | 6505 | 10.10 |
| 10 | 1052 | 6439 | 6.12 |
| 11 | 1062 | 5426 | 5.11 |
| 12 | 169 | 4341 | 25.69 |
| 13 | 2777 | 15183 | 5.47 |
| 14 | 0 | 0 | |
| 15 | 1027 | 14632 | 14.25 |
| 16 | 1403 | 14809 | 10.56 |
| 17 | 1403 | 8159 | 5.82 |
| 18 | 940 | 4496 | 4.78 |
| 19 | 0 | 0 | |
| 20 | 0 | 0 | |
| 21 | 1406 | 6259 | 4.45 |
| 22 | 611 | 5528 | 9.05 |
| 23 | 894 | 5217 | 5.84 |
| 24 | 1243 | 1402 | 1.13 |
| 25 | 0 | 0 | |
| Mean* | 1583 | 7648 | 7.2 |

*neglecting zero entries

bounds of oil slicks) decreases, model sensitivity to timestep increases (Table 6-2). Since the exposure time is not known prior to running a simulation, all simulations are therefore run at the minimum 3 hour timestep. The sensitivity analysis for number of points (Table 6-1) shows a significantly reduced variability at 500 points as compared to 200 points. The estimated mean value for the number of whale-oil interactions, however, does not change significantly as the number of points increases beyond 500. Although the variability of the estimate does decrease somewhat, the gain is not great compared to the increased cost of performing simulations using 1000 or 2000 points. (Simulation costs increase approximately linearly with the number of points used to represent the population.) Production runs are therefore performed using 500 points and a timestep of 3 hours.

## 7. Application Methodology

The 3 major components of the endangered whale-oil spill interaction model system are the oil spill model, the whale migration model and the diving-surfacing model. These models are run in sequence followed by a set of statistical and graphics programs to generate numbers and probabilities of whale-oil encounters. A 4-stage computational process is employed. First the oil spill model is run to generate oil spinet sizes and locations (stage 1). These data are then input to one of the whale migration models, and the time each modeled whale point spends in oil is calculated (stage 2). The diving-surfacing model converts time-in-oil to a number of surfacings in oil (encounters) for each whale point and for each spill scenario (stage 3). The average number of whale-oil encounters for a particular site and the total probability of whale-oil encounters for a planning area are then calculated (stage 4).

Since the presence or absence of whales has no influence on the movement of spilled oil, the oil spill model is run first (Figure 7-l). The location, timing and size of the hypothetical spills simulated are as specified by MMS. As determined by sensitivity tests (see Section 6), 25 spill scenarios are adequate to describe the inter-annual variability in the wind record. Accordingly, 25 oil trajectories are generated for each hypothetical spill site, varying the environmental conditions at the time of the spill. The wind field is specified by randomly selecting a year and day within the desired season, from the years covered by the historical wind record. Ice conditions vary from heavy to light with 25% of the scenarios run under heavy ice conditions, 25% under light ice conditions and 50% under normal ice conditions. Note that "heavy" and "light" are defined here as the 25% and 75% southerly observed occurrences of the ice edge, taken from LaBelle et al (1983); percent of ice cover within the ice edge is taken from Brewer et al (1977).

A continuous oil release is simulated by releasing discrete amounts of oil, or spinets, at discrete time intervals uniformly over the duration of the spill. Spill scenarios are run for 10 days after the last oil release to give each spinet a minimum of 10 days for movement and weathering. At certain locations and times of year, the oil may be trapped in or under ice, effectively preventing its weathering and limiting its movement. In these cases, the spill scenario is run until each spinet has had 10 days of movement in less than 30% ice cover, or until the oil has been transported with the ice outside the study area. Spinet sizes and locations are stored on magnetic disk at 3 hour intervals during each spill simulation for use by the whale migration models.

In stage 2, bowhead and gray whale movements are simulated for each spill scenario to determine whether any whales do encounter oil and if so, the amount of time spent in oiled waters (Figure 7-2). To reduce the required computer time, whale migrations are begun on the

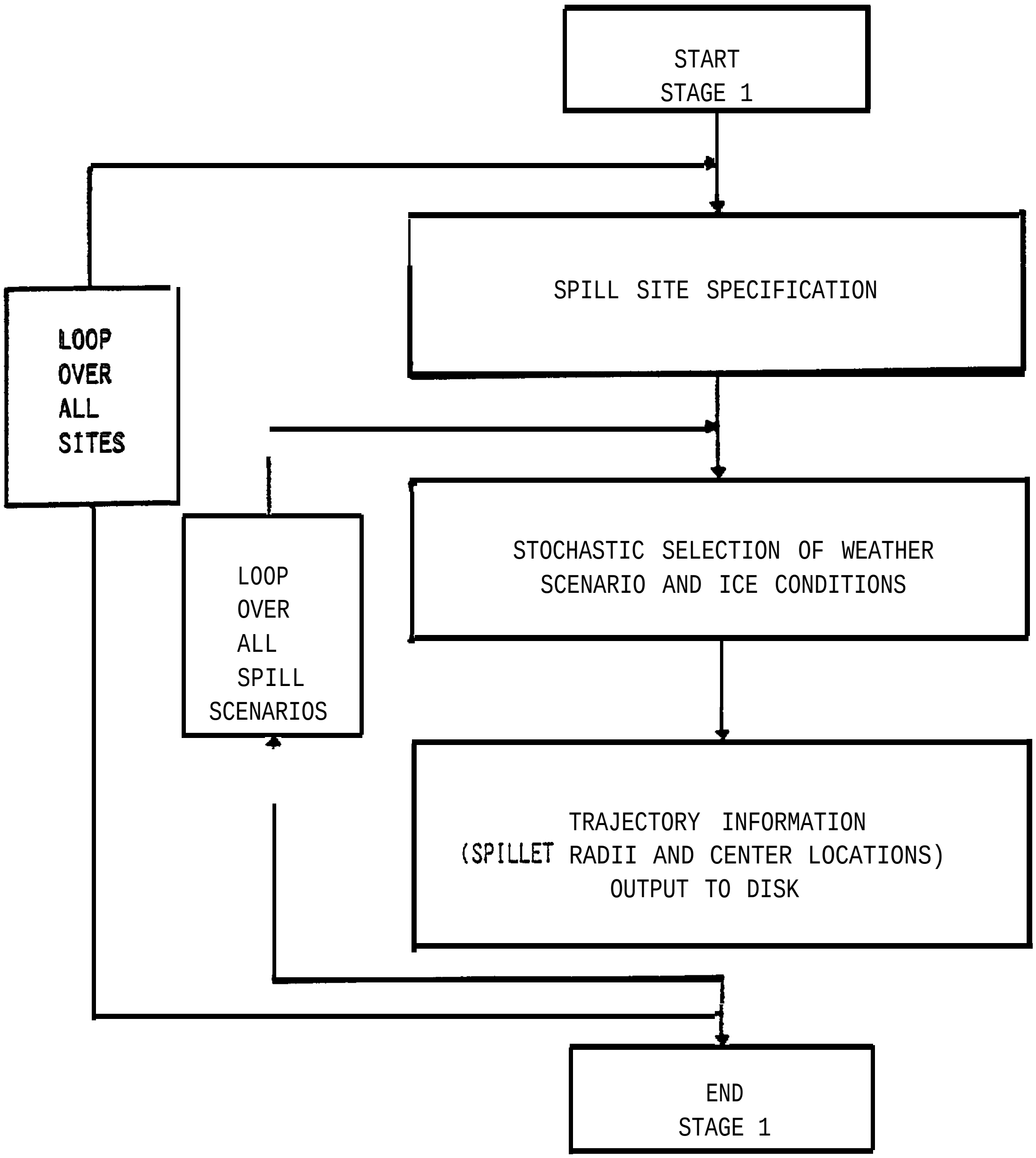



Figure 7-1. Stage 1 of the oil spill - endangered whale model system: computation of oil spill trajectories using oil spill model.

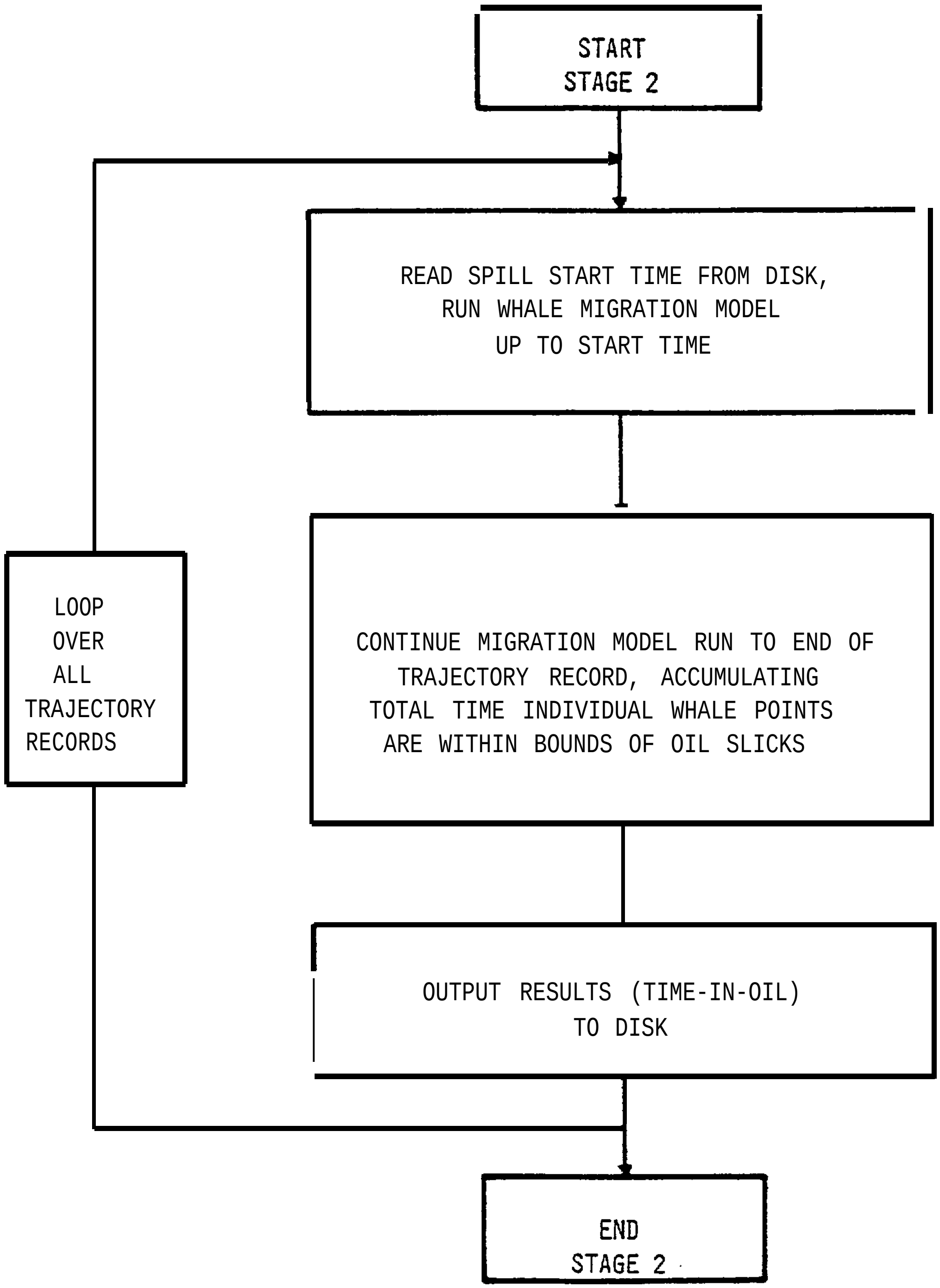



Figure 7-2. Stage 2 of the oil spill - endangered whale model system: computation of time spent by each whale point in oiled waters using whale migration model.

first day of the month preceding the month in which the spill occurs. Whale location data for the first day of each month are generated from previous migration runs for each species and are stored in separate files for each ice year type. Initializing the model from these data at least 30 days in advance of the spill allows the random component of the migration model sufficient time to generate different whale locations for each scenario.

The migration model is run until the end of the oil spill, with spill statistics input continuously over the duration of the spill from the results of stage 1. At the end of each timestep a check is performed to determine whether any of the modeled whale points have encountered oil during the timestep. If a whale point has encountered oil, the time spent in oiled waters is calculated. A running sum of time-in-oil is maintained for each modeled whale for the duration of the simulation. After 3 and 10 days of spinet movement in less than 30% ice cover, the cumulative time-in-oil of each whale point is stored.

The diving-surfacing model is then applied in stage 3 (Figure 7-3) to convert the time-in-oil of each representative whale point to an actual number of surfacings in oiled water. This process is repeated for each spill scenario at a given site.

In stage 4, the number of whale surfacings-in-oil determined for each spill scenario at each spill site is used to generate statistics of probable impacts on endangered whales. Spill impacts are determined for both individual spill sites and planning areas as a whole (Figure 7-4). For each spill site, data summarizing whale-oil encounters are presented in 2 formats: 1) the number of times oil is encountered versus percent of the population and 2) the number of surfacings in oil versus the total number of surfacings occurring over the duration of the spill. Values are calculated through both 3 and 10 days after the last oil release.

To determine the first distribution, the numbers of surfacings in oil calculated for each spill scenario are averaged over the 25 scenarios at a particular site. The number of surfacings in oil are sorted into bins or intervals of 100 surfacings in oil to preserve a measure of the relative number of oil encounters per whale. This procedure yields a distribution defining the average percent of the population encountering oil in each of the bins of 100 surfacings. Any particular spill scenario can have a greater or lesser impact than the average.

To relate the number of surfacings in oil to the total number of surfacings occurring over the period of simulations, the surfacings in oil are calculated as a percent of the total mean number of surfacings occurring for the entire population over the spill duration. For bowhead whales, we assume an average of 1637 surfacings per day per whale and a population of 3800 whales. For gray whales we assume 920 surfacings per day per whale and a population of 17,000 whales. The

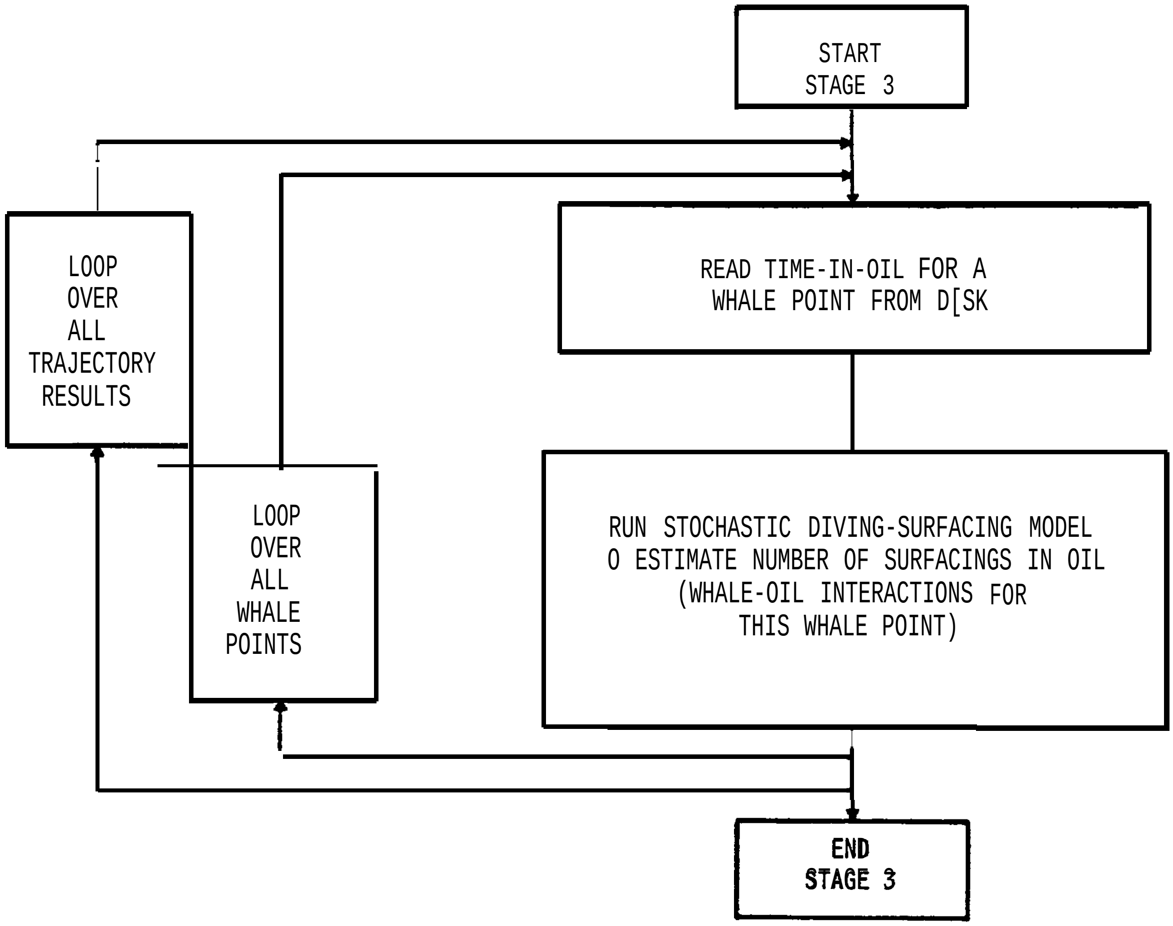



Figure 7-3. Stage 3 of the oil spill - endangered whale model system: computation of the number of surfacings in oil for each modeled whale point using the diving-surfacing model.

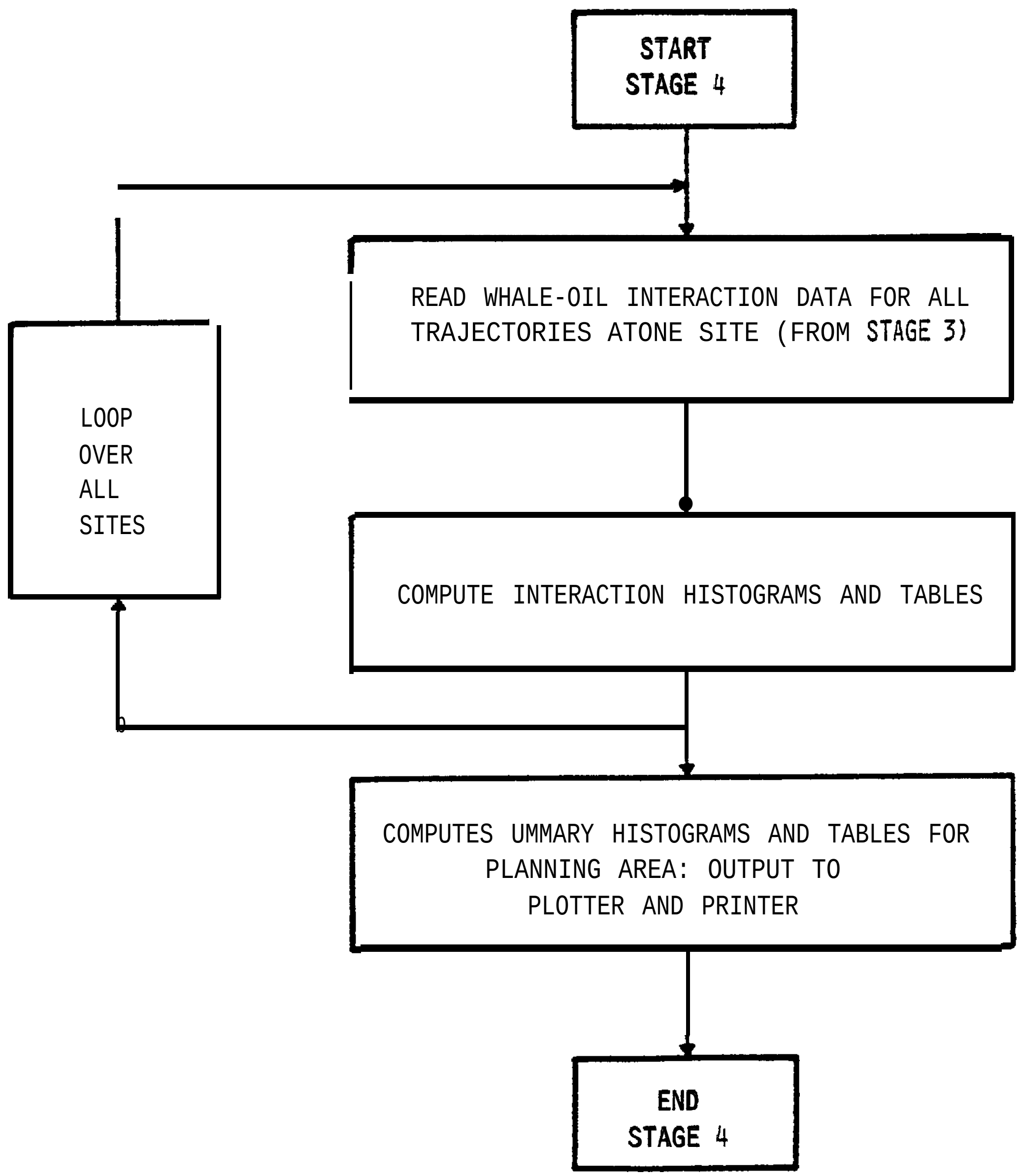



Figure 7-4. Stage 4 of the oil spill - endangered whale model system: computation of average number of encounters by spill site and total probability of encounters by planning area.

spill duration is 15 days, which allows for a 5-day release period and 10 days minimum for each spinet to be exposed to weathering. This analysis gives a measure of the portion of all whale surfacings which occur in oiled waters, averaged over all scenarios *at* a specific site, and describes how those surfacings are distributed among the affected population.

## 8. Application to Planning Areas

Four planning areas in Alaskan waters were selected by MMS for investigation of the probable impact of possible oil spills on bowhead and gray whales: the Navarin Basin, the Beaufort Sea, the Chukchi Sea and St. George Basin. For each planning area, 5 hypothetical launch points were specified for oil release. Spill size, duration and timing were also specified for each launch point.

Following the methodology described in Section 7 and using the parameter values determined in Section 6, the model system was applied to each planning area. For each spill launch point and season selected within the planning area, 25 spill scenarios were simulated. The migration models were then used to compare the movements of bowhead and gray whales with the oil trajectories. Statistics of probable whale-oil encounters were generated for each hypothetical launch point.

Appendices A-D present in detail the number of times each whale point encountered oil for each spill scenario resulting in whale-oil encounters. Note that each migration simulation used 500 points to represent the whale population. Therefore for bowhead whales, each "point-oil" encounter represents 7.6 whale-oil encounters; for gray whales, each represents 34 whale-oil encounters.

### 8.1 Navarin Basin

The locations of the 5 hypothetical launch points selected by MMS for investigation in the Navarin Basin planning area are shown in Figure 8-1. Table 8-1 lists the geographic coordinates of each site, the season over which spills are considered to occur and spill sizes and release rates. Spills at launch points 1 and 4 occur over a spring season between February 1 and May 31. At the other sites spills occur over a summer season lasting from May through October or November. Trajectories for 25 spill scenarios at each of the 5 hypothetical launch points are shown in Figures 8-2 through 8-6.

Table 8-1. Specification of hypothetical spills in the Navarin Basin planning area.

| Spill Site | Spill Location Longitude (W) | Spill Location Latitude (N) | Season | Spill Volume (bbls) | Release Rate (bbls/day) |
|---|---|---|---|---|---|
| 1 | 174° 05′ | 60° 30′ | Feb l-May 31 | 10,000 | 2,000 |
| 2 | 178° 10′ | 60° 30′ | May 1-Nov 30 | 10,000 | 2,000 |
| 3 | 177° 00′ | 60° 00′ | May 1-Nov 30 | 10,000 | 2,000 |
| 4 | 177° 00′ | 590 15′ | Feb 1- May 31 | 10,000 | 2,000 |
| 5 | 176° 00′ | 62° 00′ | May l-Ott 31 | 10,000 | 2,000 |

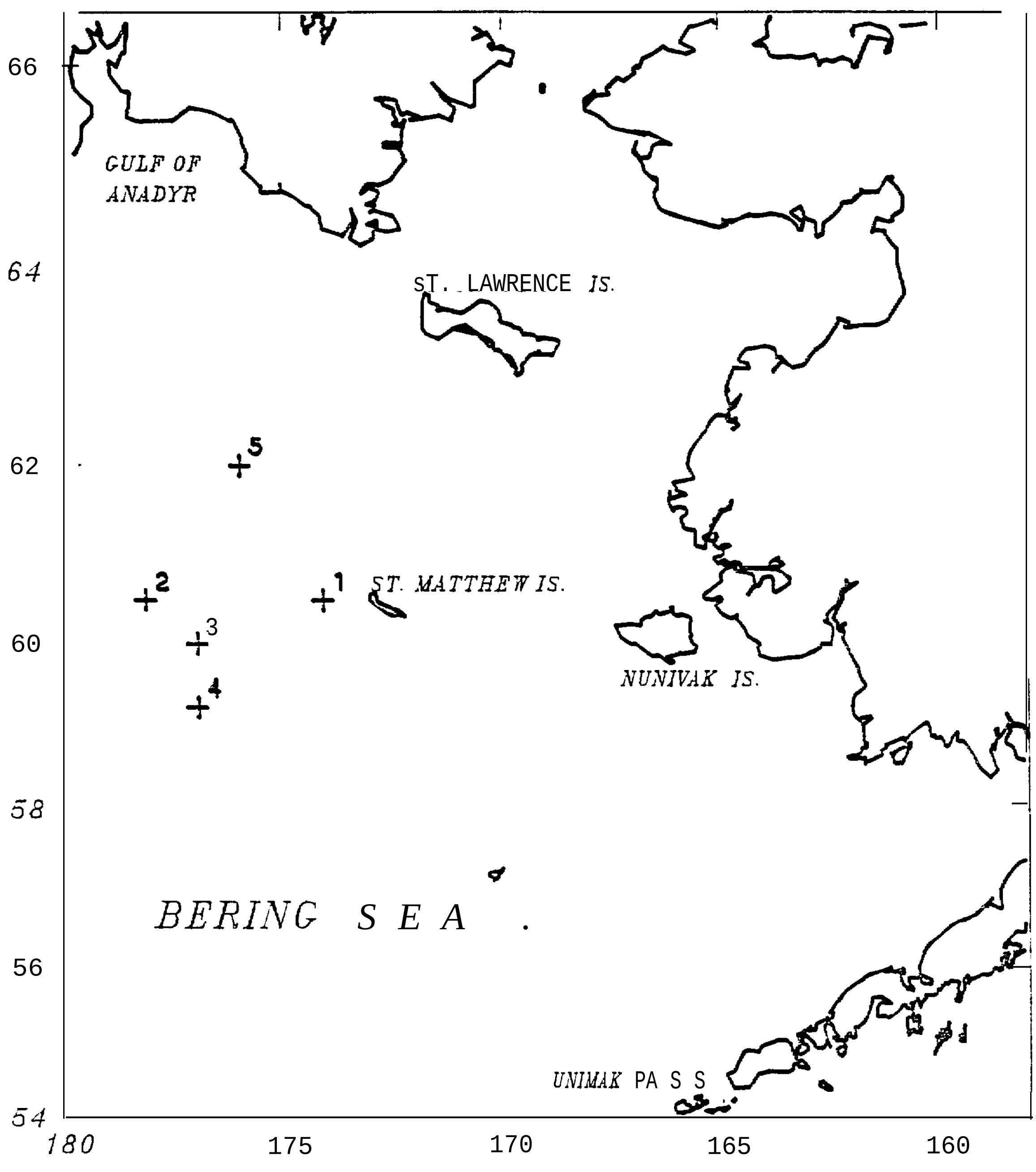



Figure 8-1. Location of the Navarin Basin planning area oil spill release sites.

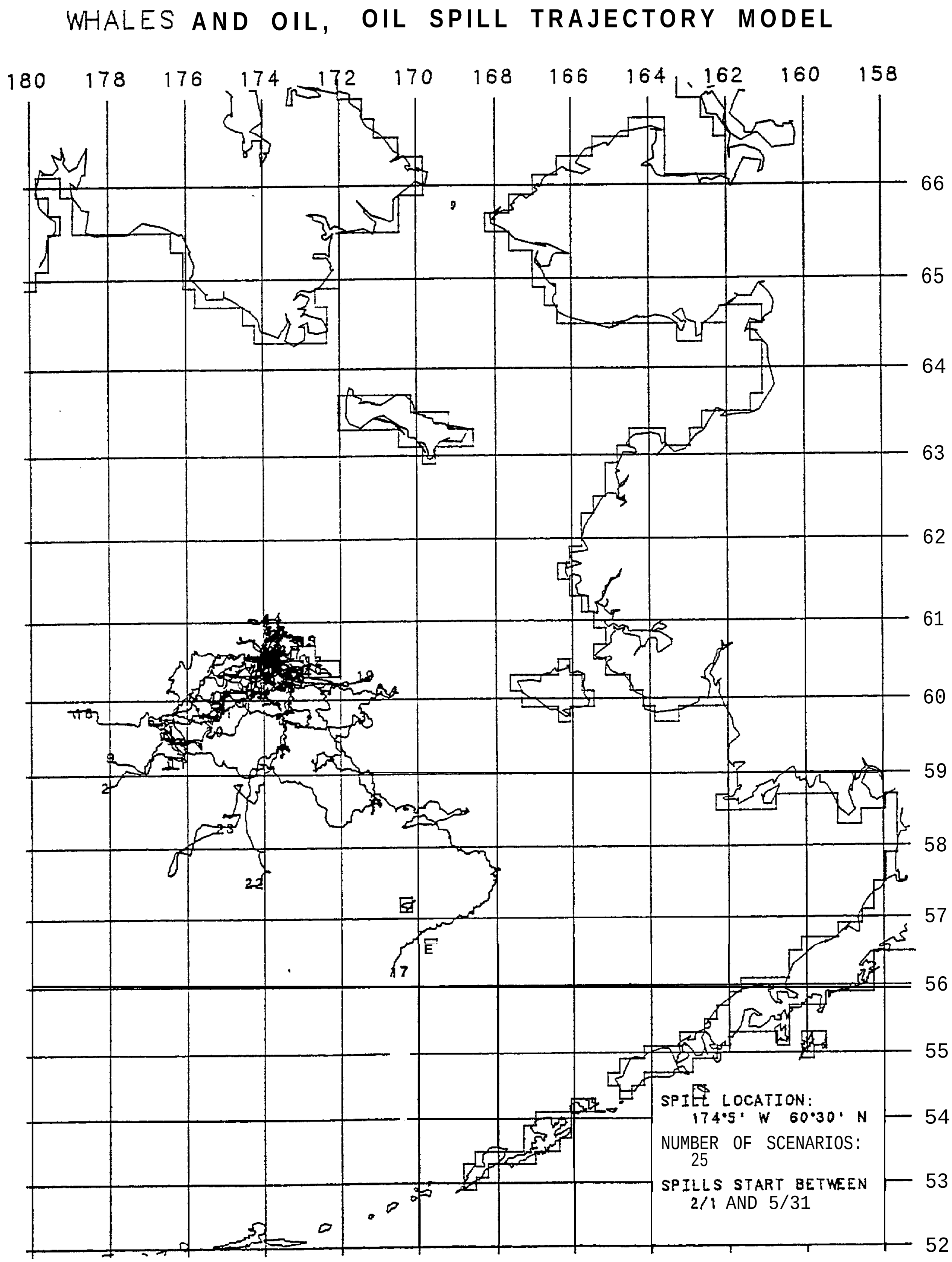



Figure 8-2. Twenty-five trajectories from Navarin site 1 (174° 5′ W, 60° 30′ N), beginning between February 1 and May 31.

## WHALES AND OIL, OIL SPILL TRAJECTORY MODEL

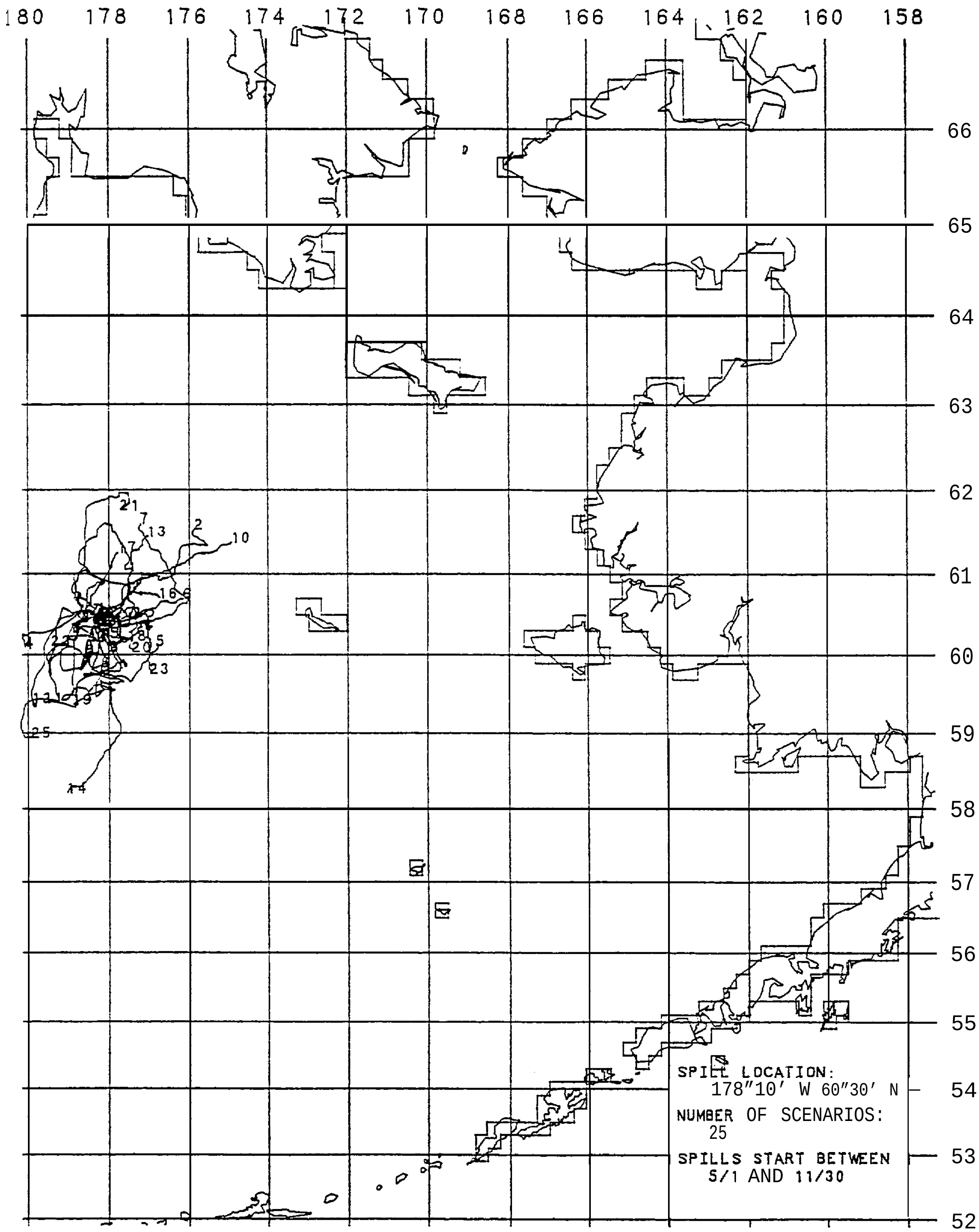



Figure 8-3. Twenty-five trajectories from Navarin site 2 (178° 10' W, 60° 30' N), beginning between May 1 and November 30.

WHALES AND OIL, OIL SPILL TRAJECTORY MODEL

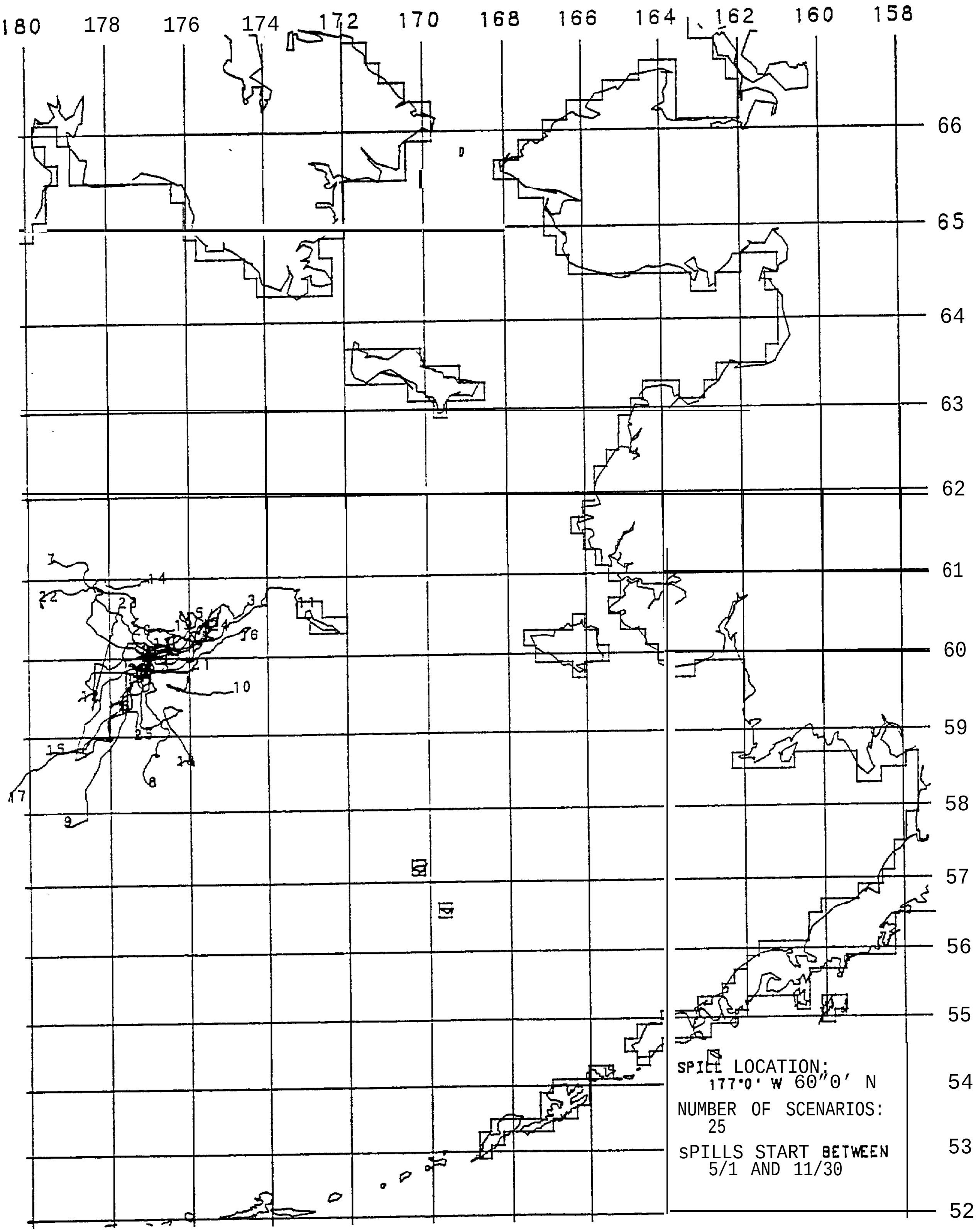



Figure 8-4. Twenty-five trajectories from Navarin site 3 (177° W, 60° N), beginning between May 1 and November 30.

WHALES AND OIL, OIL SPILL TRAJECTORY MODEL

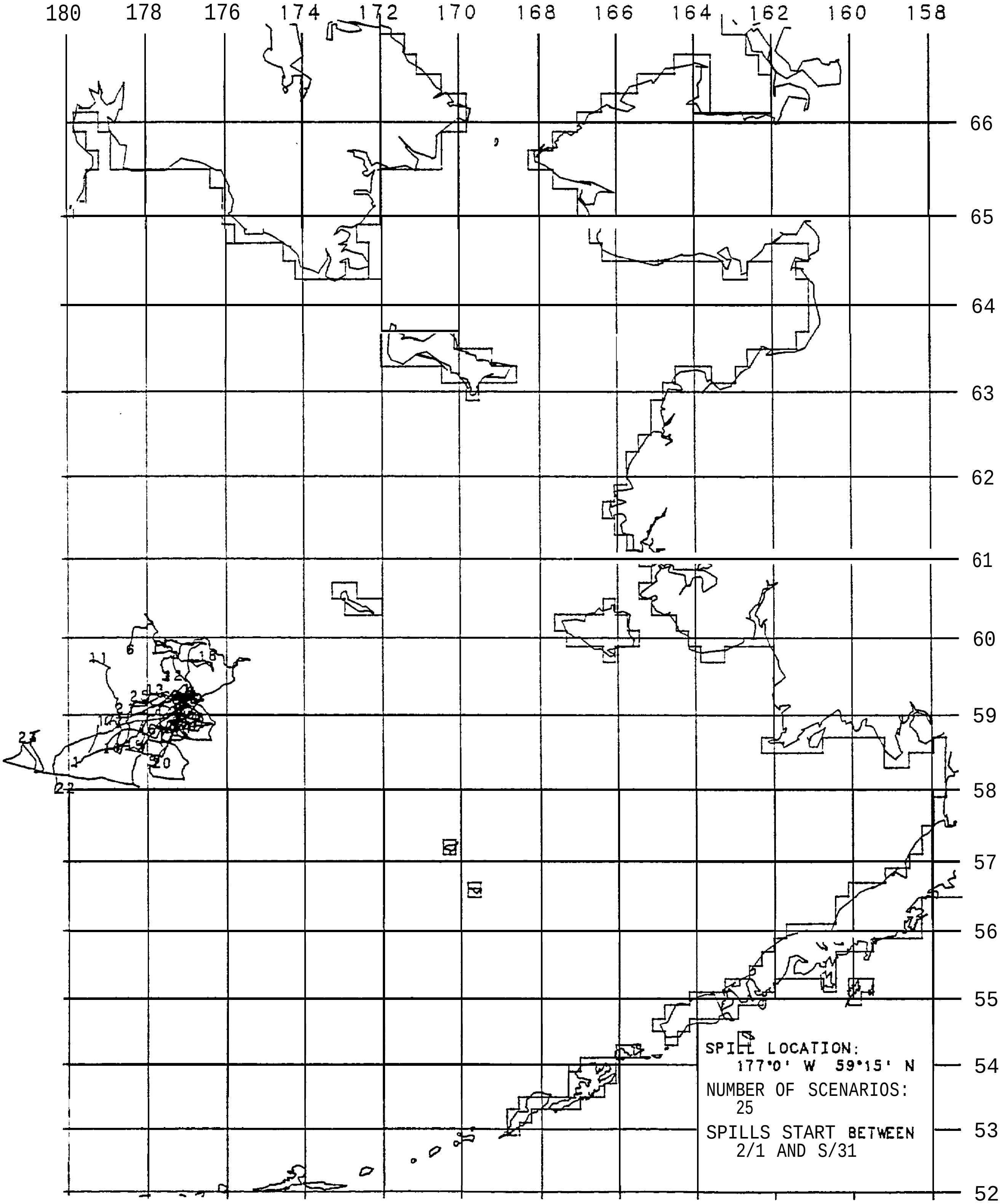



Figure 8-5. Twenty-five trajectories from Navarin site 4 (177° W, 59° 15′ N), beginning between February I and May 31.

WHALES AND OIL, OIL SPILL TRAJECTORY MODEL

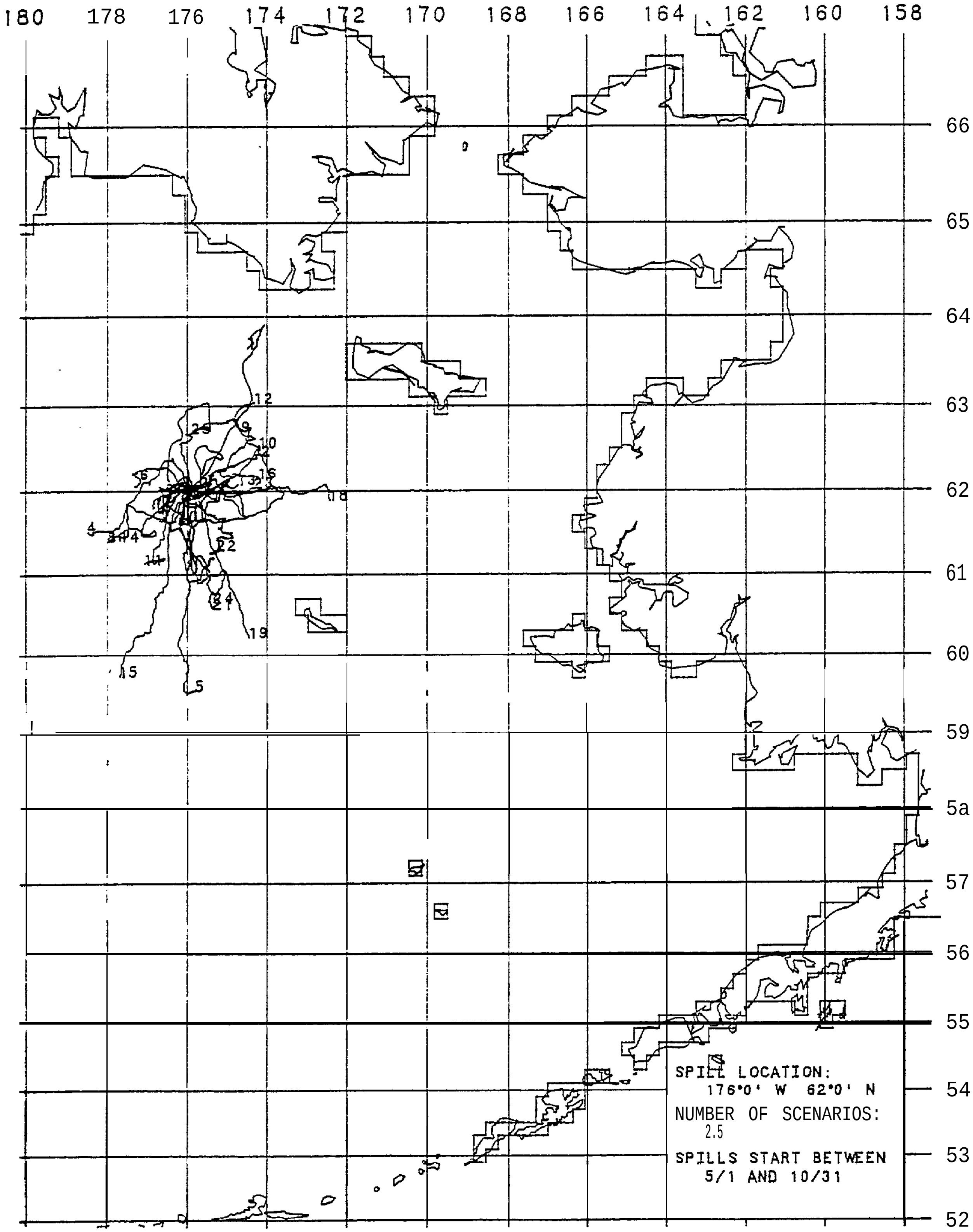



Figure 8-6. Twenty-five trajectories from Navarin site 5 (176° W, 62° N), beginning between May 1 and October 31.

Bowhead whales will be present in the Bering Sea only during the winter from approximately November through April. During this time they occupy areas in the vicinity of St. Lawrence Island, St. Matthew Island and the Gulf of Anadyr. The migration model simulates one-third of the population wintering in the vicinity of St. Matthew Island. This portion of the population is the most likely to encounter oil spilled in the Navarin Basin November through April. Any spills occurring from May through October will have no impact on the bowhead population since the whales will be north of Bering Strait.

Gray whales begin entering the Bering Sea through Unimak Pass in April. Once in the Bering Sea they remain close to the Alaskan coastline until reaching Nunivak Island. According to the simulated migration they proceed to St. Lawrence Island after rounding Nunivak Island, remaining well east of the predicted spill trajectories (Figures 8-2 through 8-5). Gray whales bound to or from the Gulf of Anadyr could possibly intersect the oil trajectories which move north and/or east of spill launch point 5 (Figure 8-6). The migration pathways followed by gray whales leaving the Bering Sea in the autumn are less well-defined than those used in the spring, but still remain to the northeast of St. Matthew Island. Predominant winds in the autumn are to the south and west which would serve to keep any spilled oil outside the major migration corridors.

The number of spill scenarios at each launch point resulting in whale-oil encounters is given in Table 8-2. The number of times each modeled whale point encountered oil is given in Appendix A for each spill scenario resulting in whale-oil encounters.

Table 8-2. Number of spill scenarios resulting in whale-oil encounters for each site in the Navarin Basin planning area.

| | | Number of spill scenarios (out of 25) resulting in whale-oil encounters | |
|---|---|---|---|
| Spill Site | Season | Bowhead | Gray |
| 1 | Feb 1 - May 31 | 19 | 0 |
| 2 | May 1 - Nov 30 | 0 | 0 |
| 3 | May 1 - Nov 30 | 0 | 0 |
| 4 | Feb 1 - May 31 | 1 | 0 |
| 5 | May 1 - Ott 31 | 0 | 0 |

Table 8-3 presents the percentage of the population which will typically encounter oil spilled at each of the 5 launch points over the seasons specified in Table 8-1. The percentage of the population encountering oil is further subdivided by the number of surfacings in oil. In Table 8-4 the number of surfacings in oil are presented as a percentage of the total number of surfacings occurring while oil is present. Spills at site 1 were encountered by an average of 1.3% of the bowhead whales. (Detailed tables of results for each simulation are included in Appendix A.) These spills, occurring between February and April, impact the whales over-wintering near St. Matthew Island. One spill trajectory of the 25 scenarios simulated at site 4 was encountered by a small number of bowhead whales. Averaged over 25 simulations, fewer than 0.1% of the animals encounter oil spilled at launch point 4.

None of the oil trajectories simulated from the Navarin sites impacted gray whales. Gray whales tend to remain to the north and east of the areas covered by spilled oil and so contact is unlikely. One sensitivity run to model timestep used a spill beginning in June at launch point 5. This simulation did indicate several gray whales contacting oil. Therefore, although the set of 25 scenarios selected stochastically at launch point 5 produced no contact of gray whales and oil, such contact does have some low probability of occurring.

The *accuracy* of the model system results relies in part on the ability of the models to produce realistic whale distributions. Only sparse data exist to quantitatively describe the distribution of either species in the Navarin Basin. For bowhead whales, there exist only March sighting data indicating whales near St. Lawrence and St. Matthew Islands. Sighting data are lacking for bowhead whales from November through February, although some portion of the population is thought to overwinter in this general area. The actual movements of bowhead whales over the winter are unknown. No bowhead whale density estimates are available. Sightings of gray whales in the Navarin Basin have only been made in November (Brueggeman et al, 1984). The migrations models replicate the observations of whale distributions, when available, and distribute whales according to their hypothesized locations when observations are lacking. To this extent, the model system predictions are consistent with our current understanding of bowhead and gray whale migration patterns in the Navarin Basin planning area.

## 8.2 Beaufort Sea

Five sites in the Beaufort Sea (Figure 8-7) were selected by MMS for investigation of the impacts on the bowhead and gray whale populations should a spill originate from one of them. The locations, timing and sizes of the hypothetical spills are given in Table 8-5. For 2 of the sites (sites 2 and 5), spills occurring over both a spring and a summer season were examined. Only summer spills were considered at the other sites. The oil trajectories for the 25 spill

Table 8-3. Summary statistics by Navarin Basin spill location of the number of bowhead whale - oil encounters by percent of the population.*

a. 3-Day Results

| Spill Site | Spill Season | Number of bowhead whale surfacings in oil: 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | >500 |
|---|---|---|---|---|---|---|---|---|
| 1 | Feb 1-May 31 | 98.9 | 0.6 | 0.3 | 0.1 | 0.1 | + | + |
| 2 | May 1-Nov 30 | 100.0 | | | | | | |
| 3 | May 1-Nov 30 | 100.0 | | | | | | |
| 4 | Feb 1-May 31 | 100.0 | + | | | | | |
| 5 | May 1-Ott 31 | 100.0 | | | | | | |

b. 10-Day Results

| Spill Site | Spill Season | Number of bowhead whale surfacings in oil: 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | >500 |
|---|---|---|---|---|---|---|---|---|
| 1 | Feb 1-May 31 | 98.7 | 0.6 | 0.3 | 0.1 | 0.1 | + | + |
| 2 | May 1-Nov 30 | 100.0 | | | | | | |
| 3 | May 1-Nov 30 | 100.0 | | | | | | |
| 4 | Feb 1-May 31 | 100.0 | + | | | + | + | |
| 5 | May 1-Ott 31 | 100.0 | | | | | | |

* Results are presented to the nearest 0.1%. A '+' designates a value greater than 0.0 but less than 0.1%.

Table 8-4. Summary statistics by Navarin Basin spill location of the number of bowhead whale surfacings in oil as a percent of the total number of surfacings occurring while oil is present.

a. 3-Day Results

| | | Number of bowhead whale surfacings in oil | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Spill Site | Spill Season | 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | >500 |
| 1 | Feb l-May 30 | 99,9855 | 0.0070 | 0.0036 | 0.0014 | 0.0013 | 0.0004 | 0.0007 |
| 2 | May 1-Nov 30 | 100.0 | | | | | | |
| 3 | May 1-Nov 30 | 100.0 | | | | | | |
| 4 | Feb l-May 31 | 99.9999 | 0.0001 | | | | | |
| 5 | May l-Ott 31 | 100.0 | | | | | | |

b. 10-Day Results

| | | Number of bowhead whale surfacings in oil | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Spill Site | Spill Season | 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | >500 |
| 1 | Feb l-May 31 | 99.9902 | 0.0047 | 0.0026 | 0.0007 | 0.0007 | 0.0004 | 0.0008 |
| 2 | May 1-Nov 30 | 100.0 | | | | | | |
| 3 | May 1-Nov 30 | 100.0 | | | | | | |
| 4 | Feb l-May 31 | 99.9996 | 0.0002 | | | 0.0001 | 0.0001 | |
| 5 | May l-Ott 31 | 100.0 | | | | | | |

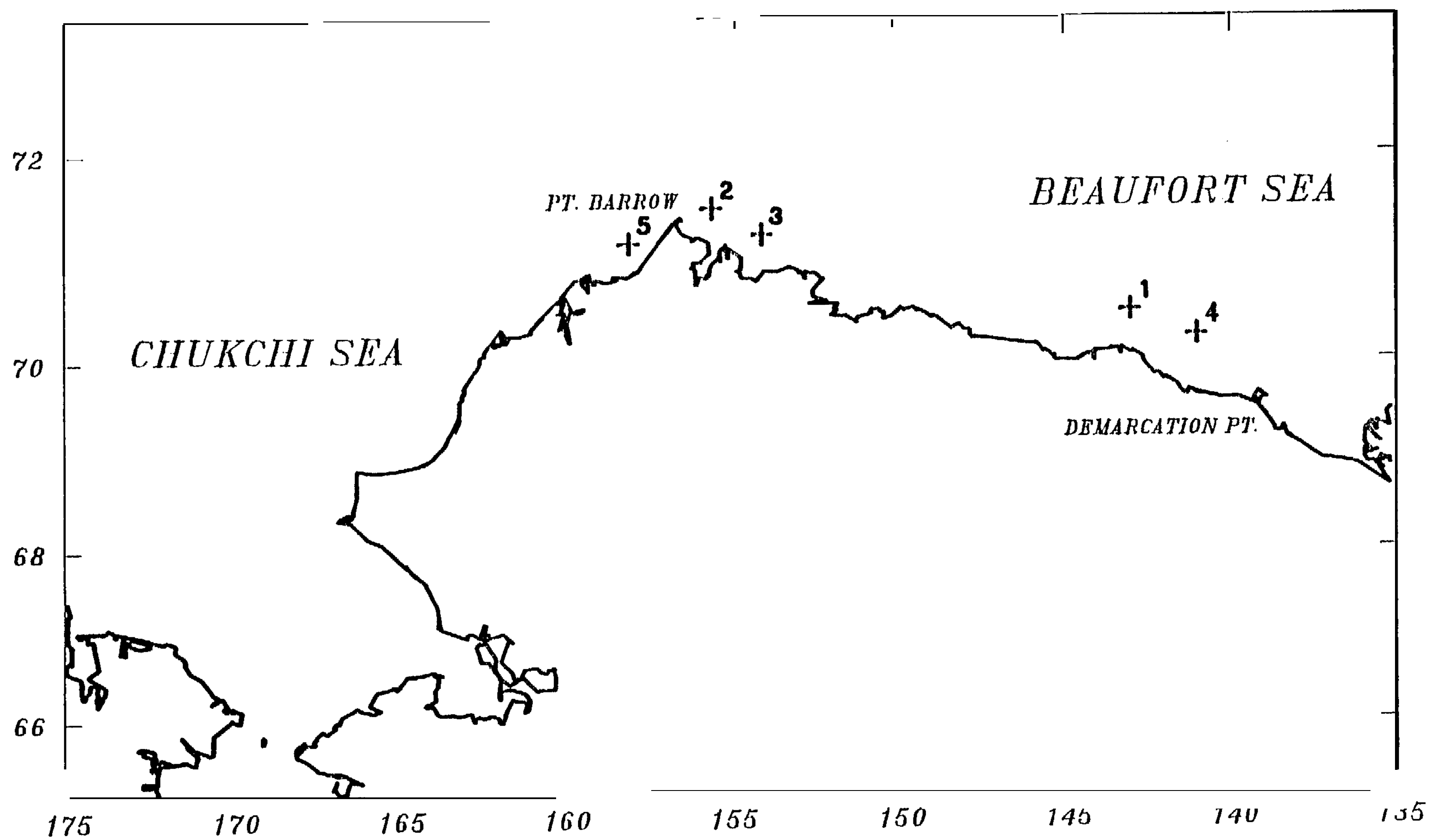



Figure 8-7. Location of the Beaufort Sea planning area oil spill release sites.

Table 8-5. Specification of hypothetical spills in the Beaufort Sea planning area.

| Spill Site | Spill Location Longitude (W) | Latitude (N) | Season | Spill Volume (bbls) | Release Rate (bbls/day) |
|---|---|---|---|---|---|
| 1 | 143° | 700 30′ | Aug 1 - Ott 31 | 10,000 | 2,000 |
| 2 | 155° 30′ | 71° 30′ | Apr 1 - Jun 30 | 10,000 | 2,000 |
| | 155° 30′ | 71° 30′ | Aug 1 - Ott 31 | 10,000 | 2,000 |
| 3 | 154° | 71° 15′ | Aug 1 - Ott 31 | 10,000 | 2,000 |
| 4 | 141° | 700 15′ | Aug 1 - Ott 31 | 10,000 | 2,000 |
| 5 | 158° | 71° 10′ | Apr 1 - Jun 30 | 10,000 | 2,000 |
| | 158° | 71° 10′ | Aug 1 - Ott 31 | 10,000 | 2,000 |

scenarios simulated for each site and season are shown in Figures 8-8 through 8-14.

Bowhead whales utilize the Alaskan Beaufort Sea at 2 different times of the year during their annual migration. In April, May and early June they pass Pt. Barrow en route to the eastern Beaufort Sea. Due to constraints by ice, the migration paths are fairly well defined. During this period bowhead whales would be susceptible to spring oil releases from sites 2 and 5. The fall migration back to the Bering Sea occurs during September and October. Migrating whales pass close to the 5 hypothetical spill sites, although the migration corridor is wider than that followed in the spring. Spills occuring at any site in September or October have the potential for impacting some portion of the bowhead population.

Gray whales are only rarely seen in the Beaufort Sea and the migration model does not simulate any whales east of Pt. Barrow. A portion of the gray whale population does utilize the nearby Chukchi Sea for feeding during the summer. This portion of the population could encounter oil spilled at one of the Beaufort sites near Pt. Barrow which is transported into the Chukchi Sea. Oil spilled at sites 2 and 5 in the spring could also come in contact with gray whales if the oil becomes incorporated in ice. This mechanism could hold the oil in a relatively unweathered state until summer when the ice would melt and the gray whales would arrive.

The number of spill scenarios at each site resulting in whale-oil encounters is given in Table 8-6 for both species, In Appendix B the number of times each modeled whale point encounters oil is listed for each spill scenario.

Table 8-6. Number of spill scenarios resulting in whale-oil encounters for each site and season in the Beaufort Sea planning area.

| | | Number of spill scenarios (out of 25) resulting in whale-oil encounters | |
|---|---|---|---|
| Spill Site | Season | Bowhead | Gray |
| 1 | Aug 1 - Ott 31 | 17 | 0 |
| 2 | Apr 1 - Jun 30 | 10 | 1 |
| 2 | Aug 1 - Ott 31 | 17 | 0 |
| 3 | Aug 1 - Ott 31 | 16 | 0 |
| 4 | Aug 1 - Ott 31 | 15 | 0 |
| 5 | Apr 1 - Jun 30 | 5 | 1 |
| 5 | Aug 1 - Ott 31 | 10 | 5 |

Table 8-7 presents the number of whale-oil encounters by percent of the population. For each of the 5 sites, a spill will impact an average of 1-5% of the population. Summer spills at sites 1, 2 and 4

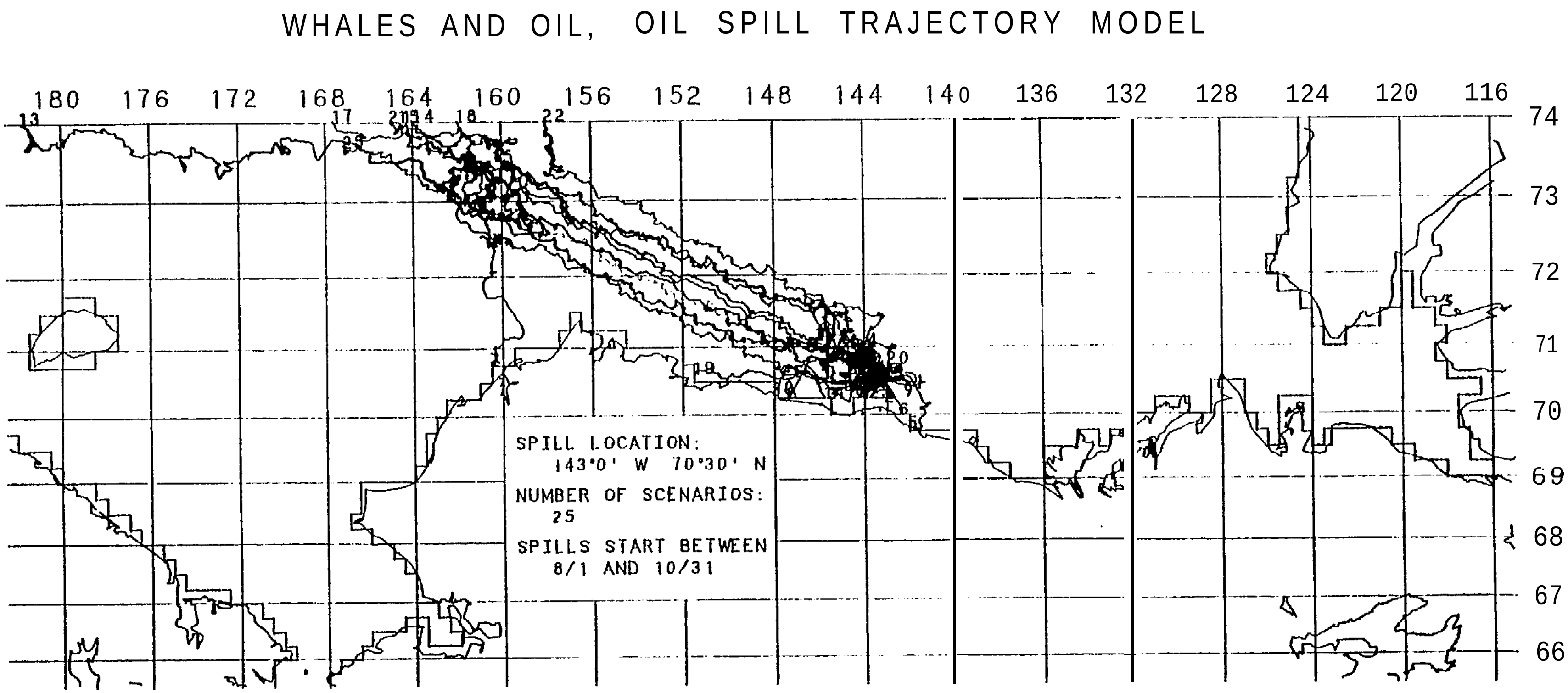



Figure 8-8. Twenty-five trajectories from Beaufort site 1 (143° W, 70° 30′ N), beginning between August 1 and October 31.

WHALES AND OIL, OIL SPILL TRAJECTORY MODEL

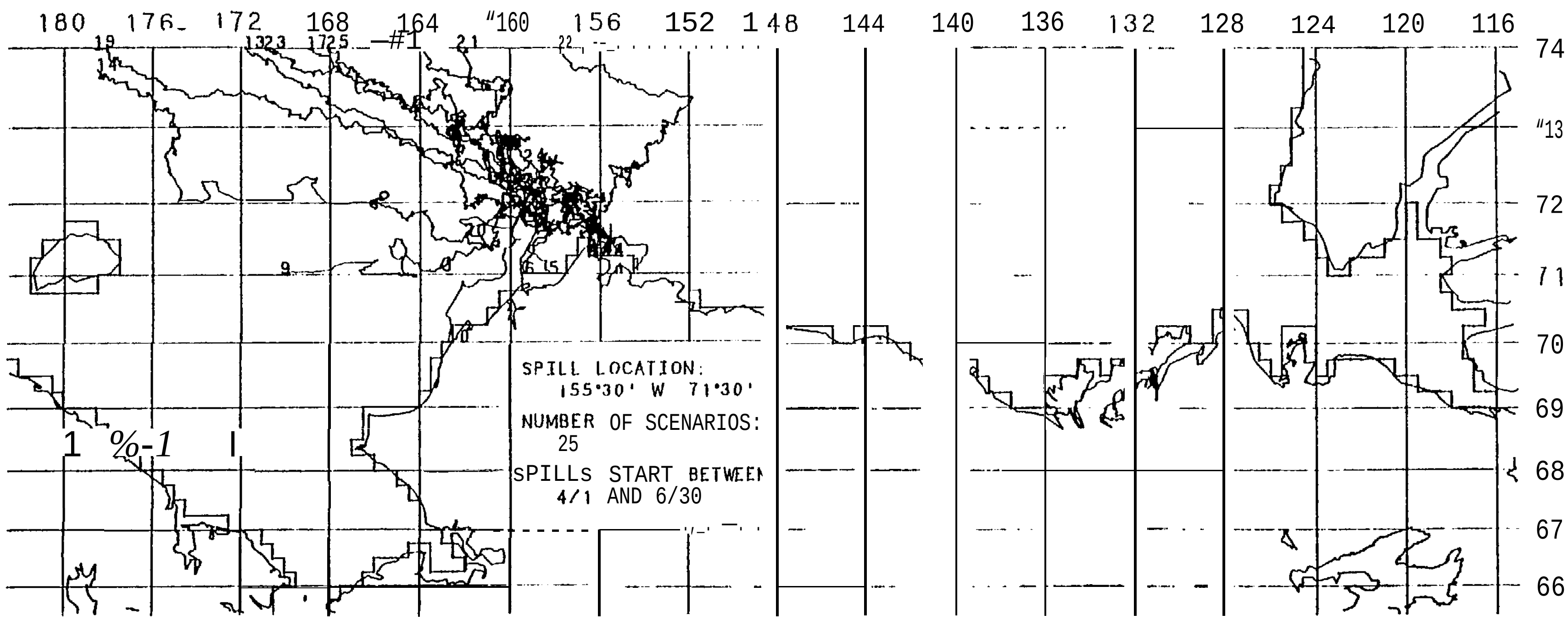



Figure 8–9. Twenty-five trajectories from Beaufort site 2 (155°30′ W, 71° 30′ N), beginning between April 1 and June 30.

WHALES AND OIL, OIL SPILL TRAJECTORY MODEL

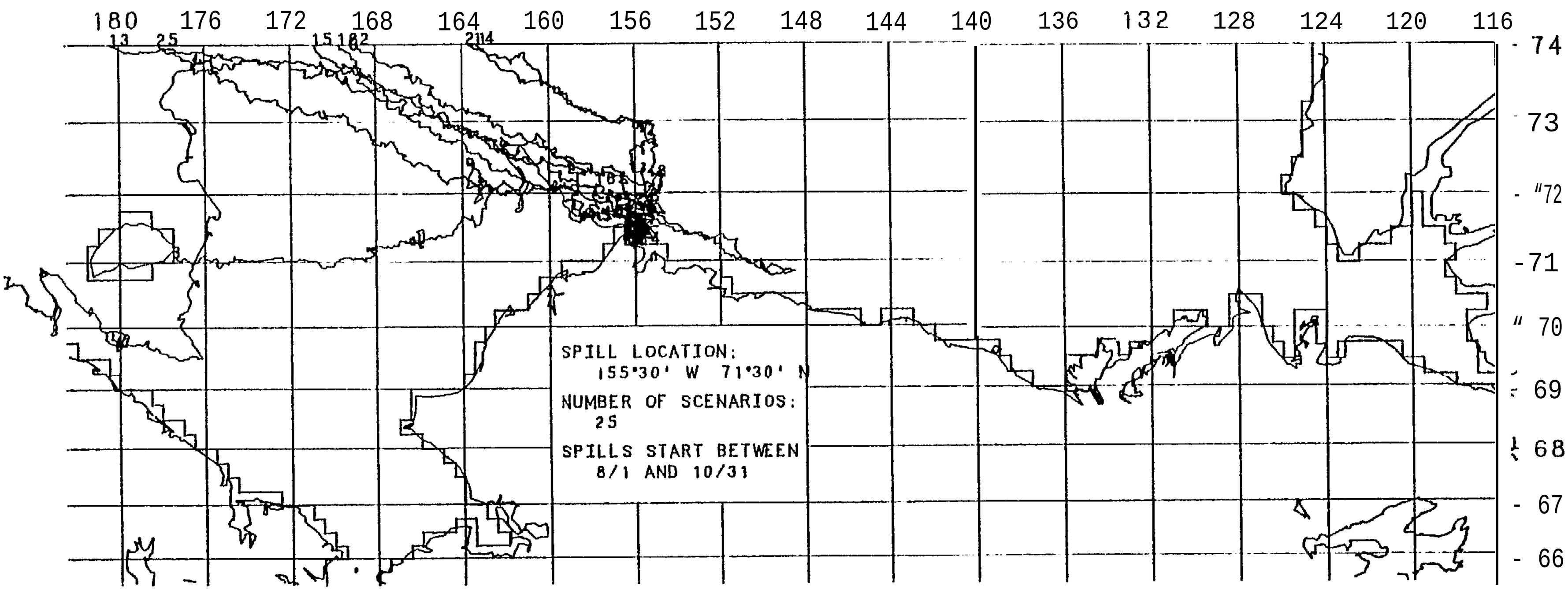



Figure 8-10. Twenty-five trajectories from Beaufort site 2 (155° 30′ W, 71° 30′ N), beginning between August 1 and October 31.

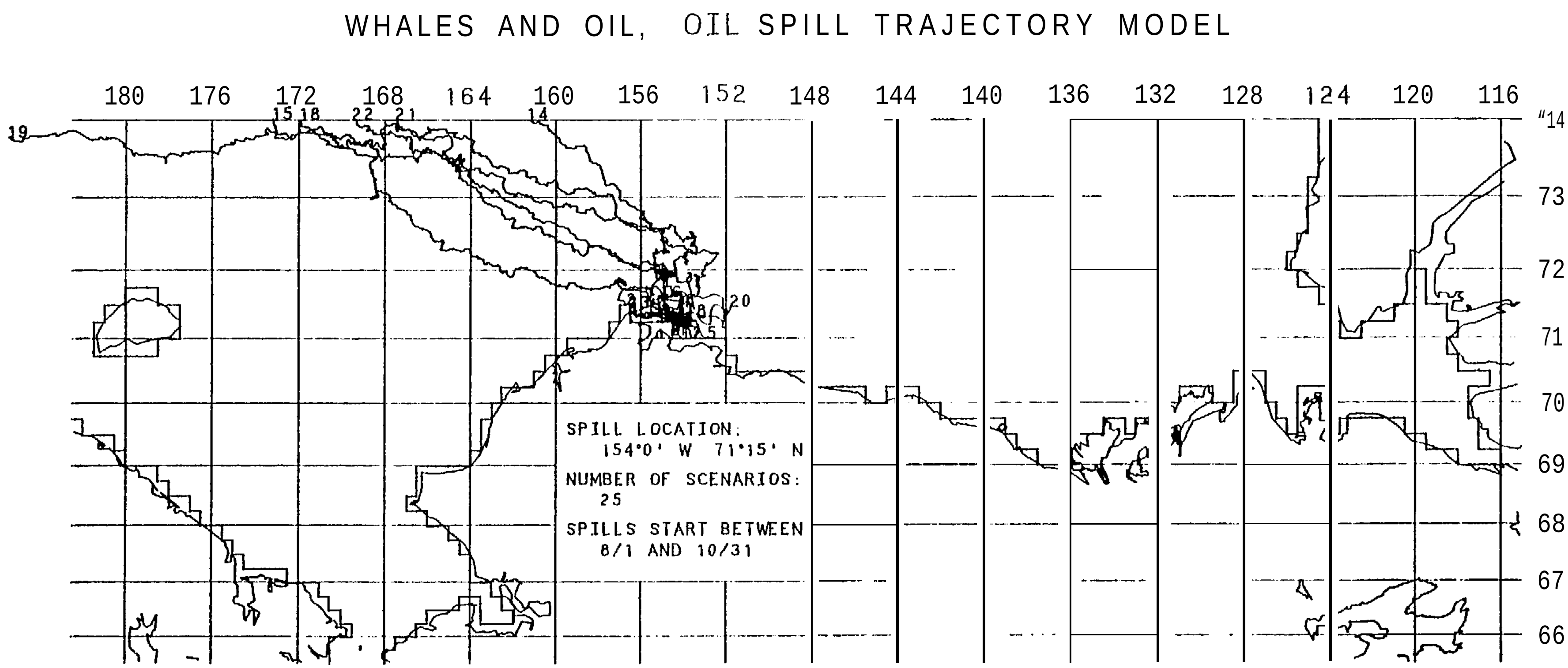



Figure 8-11. Twenty-five trajectories from Beaufort Site 3 (154° W, 71° 15' N), beginning between August 1 and October 31.

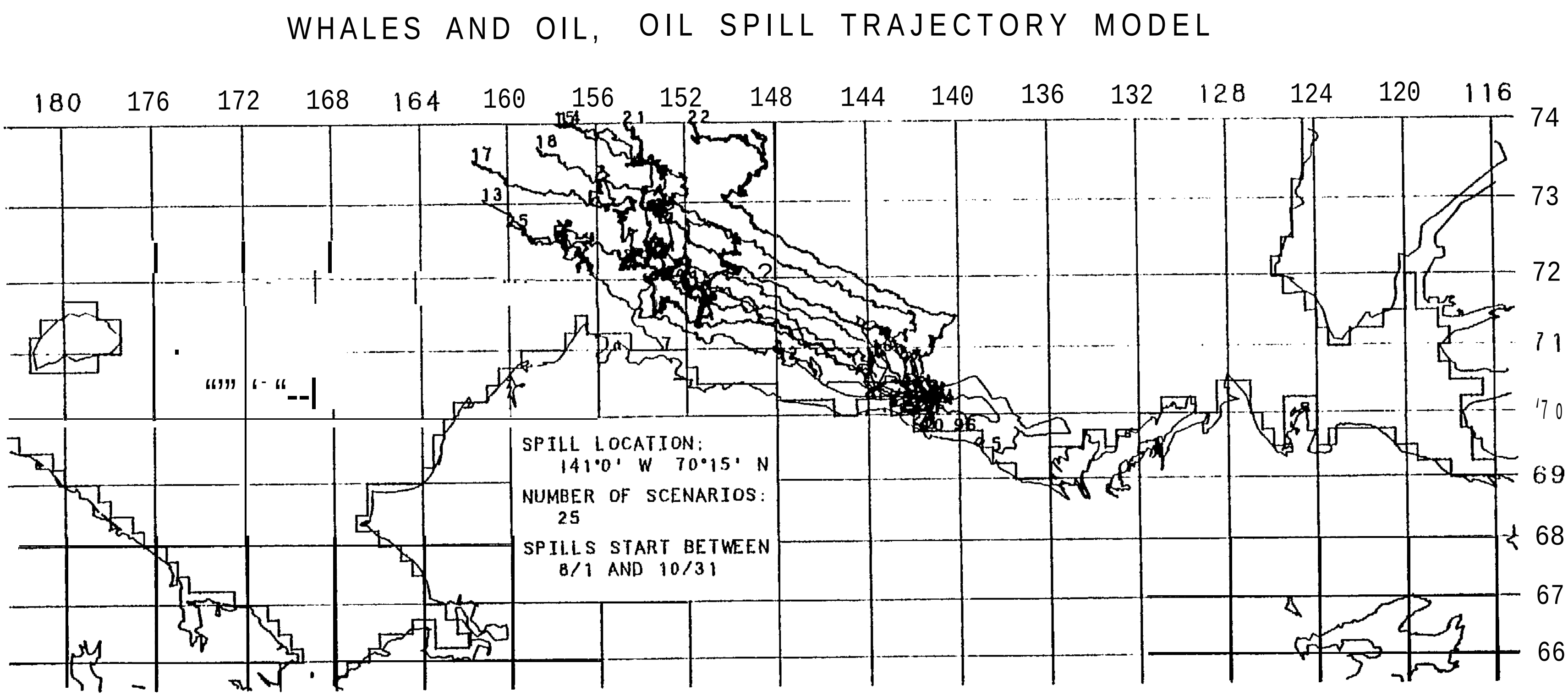



Figure 8-12. Twenty-five trajectories from Beaufort site 4 (141° W, 70° 15′ N), beginning between August 1 and October 31.

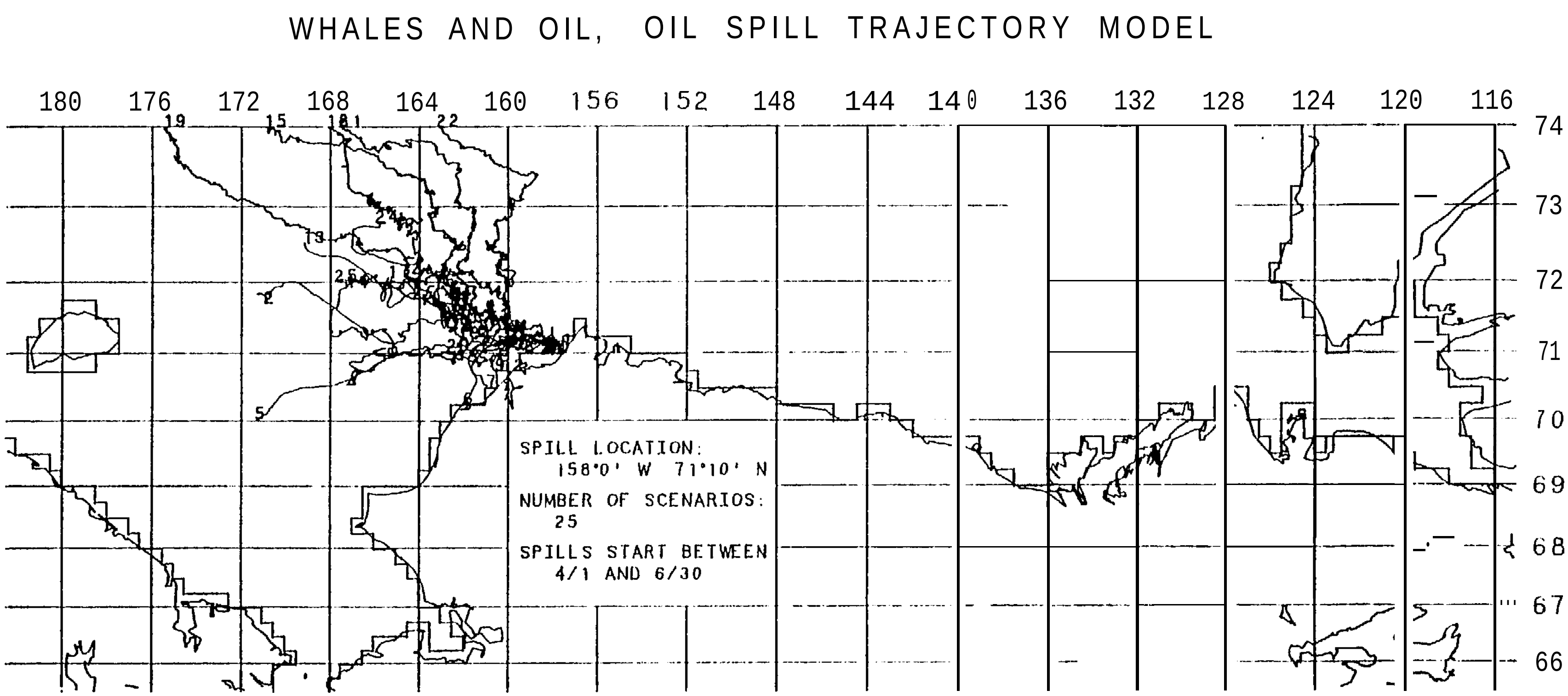



Figure 8-13. Twenty-five trajectories from Beaufort site 5 (158° W, 71° 10′ N), beginning between April 1 and June 30.

WHALES AND OIL, OIL SPILL TRAJECTORY MODEL

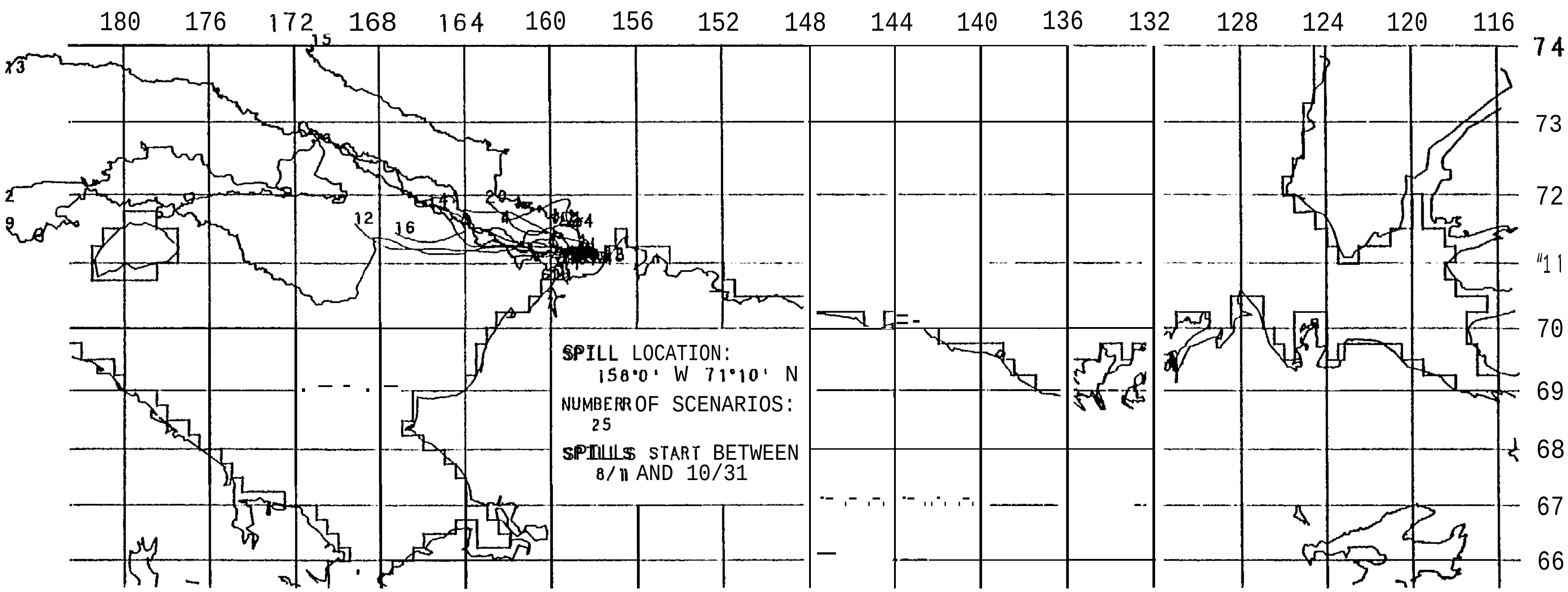



Figure 8-14. Twenty-five trajectories from Beaufort site 5 (158° W, 71° 10' N), beginning between August 1 and October 31.

Table 8-7. Summary statistics by Beaufort Sea spill location of the number of bowhead whale-oil encounters by percent of the population.*

a. 3-Day Results

| Spill Site | Spill Season | Number of bowhead whale surfacings in oil: 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | 501-600 | 601-700 | 701-800 | >800 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Aug l-Ott 31 | 95.9 | 2.4 | 1.1 | 0.4 | 0.1 | + | + | | + | + |
| 2 | Apr 1-Jun 30 | 98.5 | 0.8 | 0.4 | 0.2 | 0.1 | 0.1 | + | | | |
| 2 | Aug l-Ott 31 | 96.3 | 3.2 | 0.5 | 0.1 | + | | | | | |
| 3 | Aug 1-Oct 31 | 97.2 | 2.5 | 0.2 | | | | | | | |
| 4 | Aug l-Ott 31 | 96.6 | 0.8 | 1.1 | 0.6 | 0.4 | 0.2 | 0.1 | 0.1 | + | + |
| 5 | Apr 1-Jun 30 | 99.6 | 0.3 | 0.1 | + | | | | | | |
| 5 | Aug 1-Oct 31 | 99.0 | 0.8 | 0.1 | + | | | | | | |

b. 10-Day Results

| Spill Site | Spill Season | Number of bowhead whale surfacings in oil: 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | 501-600 | 601-700 | 701-800 | >800 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Aug l-Ott 31 | 95.4 | 2.4 | 1.2 | 0.4 | 0.2 | 0.1 | + | + | + | 0.2 |
| 2 | Apr 1-Jun 30 | 98.5 | 0.8 | 0.4 | 0.2 | 0.1 | + | + | | | |
| 2 | Aug l-Ott 31 | 96.0 | 3.3 | 0.6 | 0.1 | + | | | | | |
| 3 | Aug l-Ott 31 | 96.4 | 3.2 | 0.4 | + | | | | | | |
| 4 | Aug l-Ott 31 | 96.0 | 1.1 | 1.4 | 0,6 | 0.5 | 0.1 | 0.2 | + | + | + |
| 5 | Apr 1-Jun 30 | 99.6 | 0.3 | + | + | | | | | | |
| 5 | Aug l-Ott 31 | 98.7 | 1.1 | 0.1 | + | + | | | | | |

*Results are presented to nearest 0.1%. A "+" designates a value greater than 0.0 but less than 0.1%.

tend to impact the higher percentages of whales. Spring spills at sites 2 and 5 impact relatively fewer whales. The surfacings in oil are presented as a fraction of total surfacings occurring over the spill duration in Table 8-8. Fewer than 0.05% of all surfacings occur in oil on the average for a spill at any site.

The estimated interactions of Beaufort Sea oil spills and gray whales are shown in Tables 8-9 and 8-10. Gray whales have the greatest potential for encountering summer spills from site 5 since site 5 is actually located near the northern bound of their summer feeding range in the Alaskan Chukchi Sea. Typically 0.2% of the gray whales will encounter oil from a summer spill at site 5. Spring spills at sites 2 and 5 have a very low probability of impacting gray whales, and if encounters do occur, only a very small percentage of the population is likely to be affected (Table 8-9). Summer spills at sites 1-4 have no impact on gray whales.

The validity of model system results depends upon the extent to which modeled whale distributions reflect actual whale distributions. Modeled bowhead whale distributions in the spring near Pt. Barrow were found to agree well with observed whale densities (see Sections 2.2 and 2.4). East of 150° W modeled densities were slightly higher than observed, which, if the observed densities are correct, indicates the model system will over-estimate whale-oil encounters. However, only sites 1 and 4 lie within the region east of 150° W and spring spills were not considered for either of these sites.

In August the modeled bowhead whale densities along the Alaskan Beaufort coastline were slightly lower than observed, although still within 1 standard deviation of the mean observed values. For the period September-October, modeled densities were higher than observed by as much as 5 standard deviations from the mean in some areas. In other areas, agreement between model and observation was quite good. Modeled whale densities along the Alaskan Beaufort are fairly uniform, while observed densities are highly variable between survey areas. If the observed densities truly reflect bowhead whale distributions during the fall migration, the model system will over-estimate whale-oil encounters resulting from spills at sites 2 and 3 in September and October.

For the areas impacted by oil released from the Beaufort Sea planning area sites, very little observed gray whale density data are available for the times of interest. Modeled densities in July agree well with observed densities along the Alaskan Chukchi coastline. Therefore, the simulated *gray whale* interactions with oil spilled at sites 2 and 5 in the spring are probably reasonable estimates of the impact on the population. No density estimates are available for gray whales in the Beaufort Sea and the migration model does not simulate any whales in this area, although small numbers of gray whales have been sighted off the Tuktoyaktuk Peninsula in the Beaufort Sea (Reed et al, 1984).

Table 8-8. Summary statistics by Beaufort Sea spill location of the number of bowhead whale surfacings in oil as a percent of the total number of surfacings occurring while oil is present.

a. 3-Day Results

| Spill Site | Spill Season | Number of bowhead whale surfacings in oil: 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | 501-600 | 601-700 | 701-800 | >800 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Aug l-Ott 31 | 99.9573 | 0.0248 | 0.0110 | 0.0038 | 0.0013 | 0.0005 | 0.0002 | 0.0001 | 0.0002 | 0.0007 |
| 2 | Apr 1-Jun 30 | 99.9850 | 0.0077 | 0.0039 | 0.0018 | 0.0009 | 0.0007 | 0.0001 | | | |
| 2 | Aug l-Ott 31 | 99.9820 | 0.0154 | 0.0023 | 0.0003 | | | | | | |
| 3 | Aug l-Ott 31 | 99.9888 | 0.0101 | 0.0010 | 0.0001 | | | | | | |
| 4 | Aug 1-Oct 31 | 99.9408 | 0.0144 | 0.0191 | 0.0111 | 0.0076 | 0,0029 | 0.0015 | 0.0011 | 0.0007 | 0.0007 |
| 5 | Apr 1-Jun 30 | 99.9982 | 0.0014 | 0.0003 | 0.0001 | | | | | | |
| 5 | Aug l-Ott 31 | 99.9959 | 0.0035 | 0.0006 | | | | | | | |

b. 10-Day Results

| Spill Site | Spill Season | Number of bowhead whale surfacings in oil: 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | 501-600 | 601-700 | 701-800 | >800 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Aug l-Ott 31 | 99.9619 | 0.0194 | 0.0102 | 0.0037 | 0.0018 | 0.0005 | 0.0001 | 0.0003 | 0.0004 | 0.0017 |
| 2 | Apr 1-Jun 30 | 99.9919 | 0.0041 | 0.0022 | 0.0009 | 0.0006 | 0.0002 | 0.0001 | | | |
| 2 | Aug l-Ott 31 | 99.9895 | 0.0089 | 0.0015 | 0.0001 | | | | | | |
| 3 | Aug l-Ott 31 | 99.9920 | 0.0072 | 0.0008 | | | | | | | |
| 4 | Aug l-Ott 31 | 99.9658 | 0.0094 | 0.0116 | 0.0054 | 0.0042 | 0.0012 | 0.0014 | 0.0003 | 0.0001 | 0.0005 |
| 5 | Apr 1-Jun 30 | 99.9989 | 0.0009 | 0.0001 | 0.0001 | | | | | | |
| 5 | Aug l-Ott 31 | 99.9969 | 0.0027 | 0.0003 | | | | | | | |

Table 8-9. Summary statistics by Beaufort Sea spill location of the number of gray whale-oil encounters by percent of the population.*

a. 3-Day Results

| Spill Site | Spill Season | Number of gray whale surfacings in oil: 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | >500 |
|---|---|---|---|---|---|---|---|---|
| 1 | Aug l-Ott 31 | 100.0 | | | | | | |
| 2 | Apr 1-Jun 30 | 100.0 | + | | | | | |
| 2 | Aug l-Ott 31 | 100.0 | | | | | | |
| 3 | Aug l-Ott 31 | 100.0 | | | | | | |
| 4 | Aug l-Ott 31 | 100.0 | | | | | | |
| 5 | Apr 1-Jun 30 | 100.0 | | | | | | |
| 5 | Aug l-Ott 31 | 99.8 | 0.1 | + | | | | |

b. 10-Day Results

| Spill Site | Spill Season | Number of gray whale surfacings in oil: 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | >500 |
|---|---|---|---|---|---|---|---|---|
| 1 | Aug l-Ott 31 | 100.0 | | | | | | |
| 2 | Apr 1-Jun 30 | 100.0 | + | | | | | |
| 2 | Aug l-Ott 31 | 100.0 | | | | | | |
| 3 | Aug 1-Oct 31 | 100.0 | | | | | | |
| 4 | Aug l-Ott 31 | 100.0 | | | | | | |
| 5 | Apr 1-Jun 30 | 100.0 | | + | | | | |
| 5 | Aug l-Ott 31 | 99.8 | 0.1 | 0.1 | | + | | |

*Results are presented to nearest 0.1%. A "+" designates a value greater than 0.0 but less than 0.1%.

## 8.3 Chukchi Sea

Five sites in the Chukchi Sea were selected by MMS as possible sources of an oil release. For each site the impact of an accidental oil spill on both the gray and bowhead whale populations was investigated for spills occurring over the season(s) specified by MMS. The locations of the sites, time periods over which spills are considered to occur, and spill sizes and release rates are given in Table 8-11. The relative geographic locations of the 5 sites are shown in Figure 8-15. Oil trajectories for the 25 spill scenarios simulated at each site are shown in Figures 8-16 through 8-23.

Bowhead whales are present in the Chukchi Sea in the spring and late autumn on their way to and from the Beaufort Sea. During the spring migration in April and May the whales remain close to the Alaskan coastline, following leads and cracks in the ice. Due to the constraints imposed by the ice, the migration pathways are relatively narrow. In the autumn bowhead whales cross the Chukchi Sea to follow the Soviet coastline south to the Bering Sea. The migration routes across the Chukchi Sea are not well known. The migration model simulates 2 alternate routes, allowing the modeled whales to move within fairly broad corridors.

Gray whales are typically present in the Chukchi Sea from July through October, depending on ice conditions. The migration model simulates approximately 20% of the gray whale population feeding along the Alaskan coast of the Chukchi Sea in the summer. Only this portion of the population is likely to be affected by oil spilled at Chukchi sites 1, 3, 4 and 5. Some spills from site 2 move toward the Soviet coastline; the portion of the gray population which feeds in Soviet waters could possibly encounter this oil.

Table 8-12 gives the number of spill scenarios resulting in whale-oil encounters for the 25 scenarios simulated for each site and season. The number of times each modeled whale point encountered oil and the time spent in oiled water is given in Appendix C for each spill scenario resulting in whale-oil encounters.

The results of the bowhead whale migration simulations are summarized in Tables 8-13 and 8-14. Summer spills at site 3 had no impact on the bowhead whales. An average of 1.5% of the population is likely to encounter oil released during a spring spill at site 3. Spills at the other sites can be expected to impact less than 1% of the population on the average. In all cases the number of surfacings in oil represent an extremely small fraction of the total number of surfacings occurring over the spill duration (Table 8-14).

Simulations of gray whale movements indicate gray whales encounter oil spilled from all the Chukchi sites except site 1 spills in the spring and site 2 spills. Summer spills at site 5 result in 1.4% of the population encountering oil (Table 8-15). Spills at the other

Table 8-11. Specification of hypothetical spills in the Chukchi Sea planning area.

| Spill Site | Spill Location Longitude (W) | Latitude (N) | Season | Spill Volume (bbls) | Release Rate (bbls/day) |
|---|---|---|---|---|---|
| 1 | 159° 30′ | 7(-J0 50′ | Apr 1 - Jun 1 | 10,000 | 2,000 |
| | 159° 30′ | 700 50′ | Jun 30 - Ott 31 | 10,000 | 2,000 |
| 2 | 168° 55′ | 70° 30′ | Aug 1 - Ott 30 | 10,000 | 2,000 |
| 3 | 167° | 68° 45′ | Mar 1 - Jun 1 | 10,000 | 2,000 |
| | 167° | 68° 45′ | Jun 30 - Ott 31 | 10,000 | 2,000 |
| 4 | 163° | 70° | Jun 1 - Ott 31 | 10,000 | 2,000 |
| 5 | 164° | 69° 30′ | Jun 1 - Ott 31 | 10,000 | 2,000 |
| | 164° | 69° 30′ | Ott 2 - Jan 30 | 10,000 | 2,000 |

Table 8-12. Number of spill scenarios resulting in whale - oil encounters for each site in the Chukchi Sea planning area.

| | | Number of spill scenarios (out of 25) resulting in whale-oil encounters | |
|---|---|---|---|
| Spill Site | Season | Bowhead | Gray |
| 1 | Apr 1 - Jun 1 | 10 | 0 |
| 1 | Jun 30 - Ott 31 | 8 | 8 |
| 2 | Aug 1 - Ott 31 | 6 | 0 |
| 3 | Mar 1 - Jun 1 | 10 | 4 |
| 3 | Jun 30 - Ott 31 | 0 | 8 |
| 4 | Jun 1 - Ott 31 | 4 | 16 |
| 5 | Ott 2 - Jan 30 | 0 | 19 |
| 5 | Jun 1 - Ott 1 | 3 | 8 |

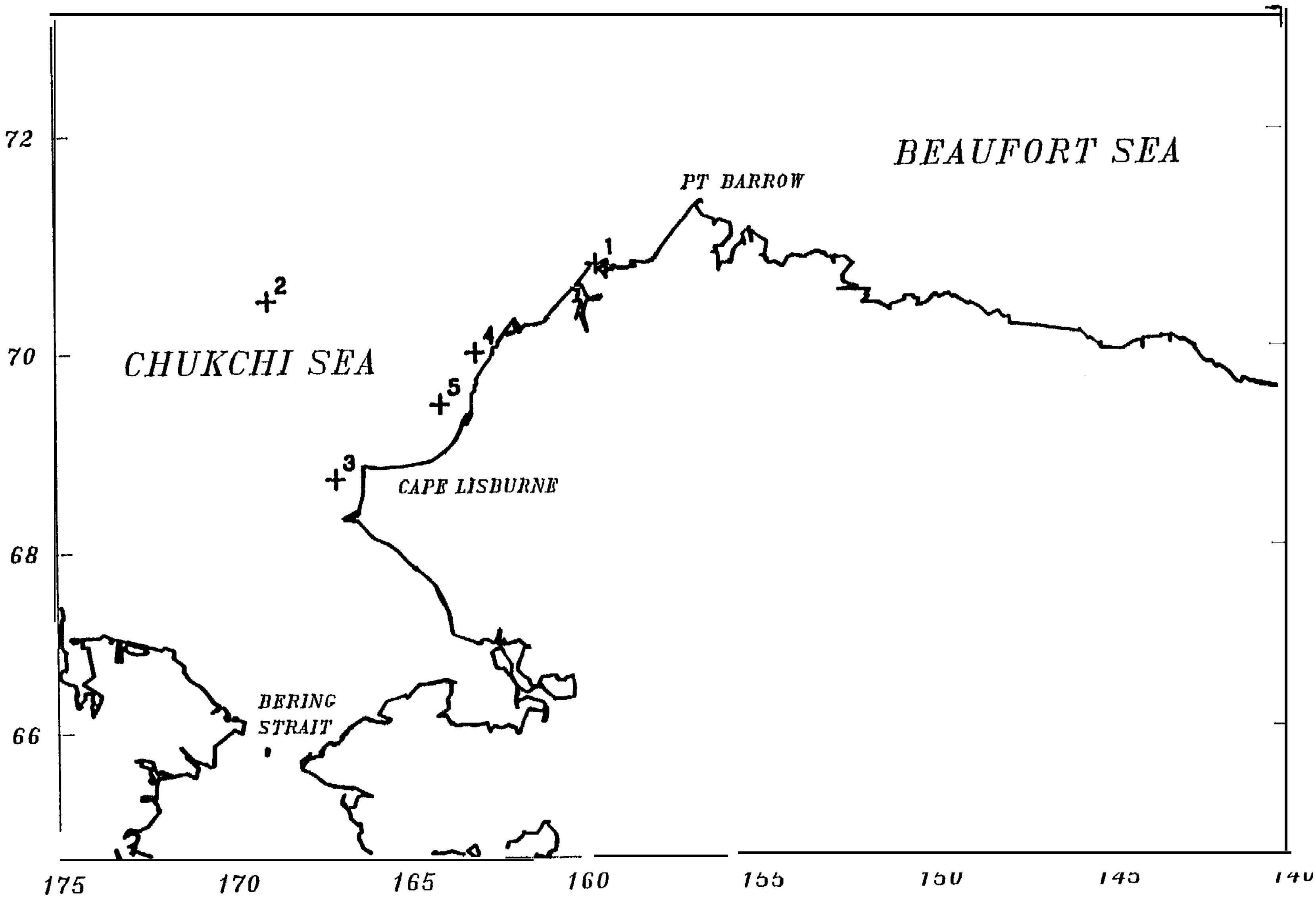



Figure 8-15. Location of the Chukchi Sea planning area oil spill release sites.

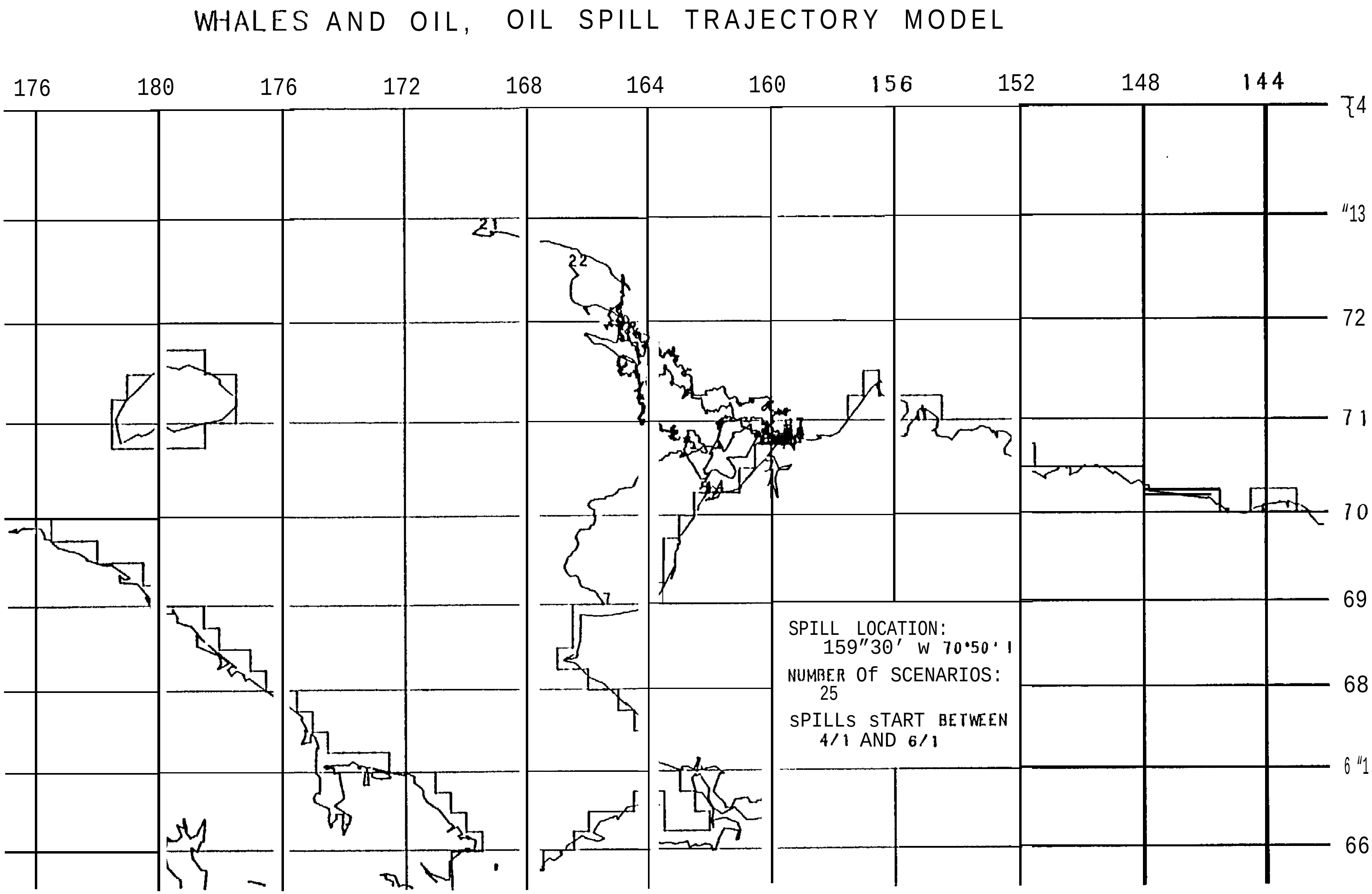



Figure 8-16. Twenty-five trajectories from Chukchi site 1 (159° 30′ W, 70° 50′ N), beginning between April 1 and June 1.

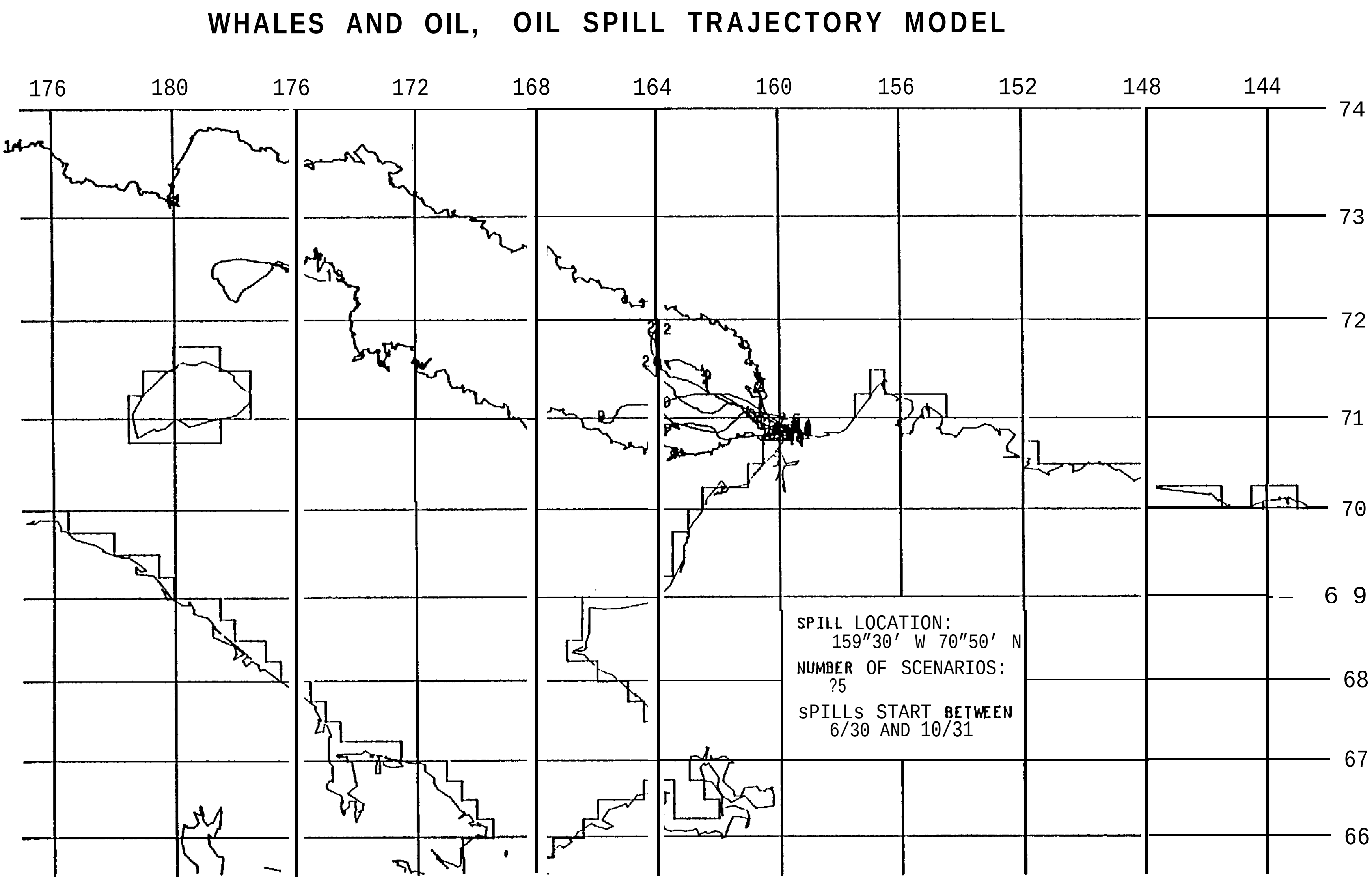



Figure 8–17. Twenty-five trajectories from Chukchi site 1 (159° 30′ W, 70° 50′ N), beginning between June 30 and October 31.

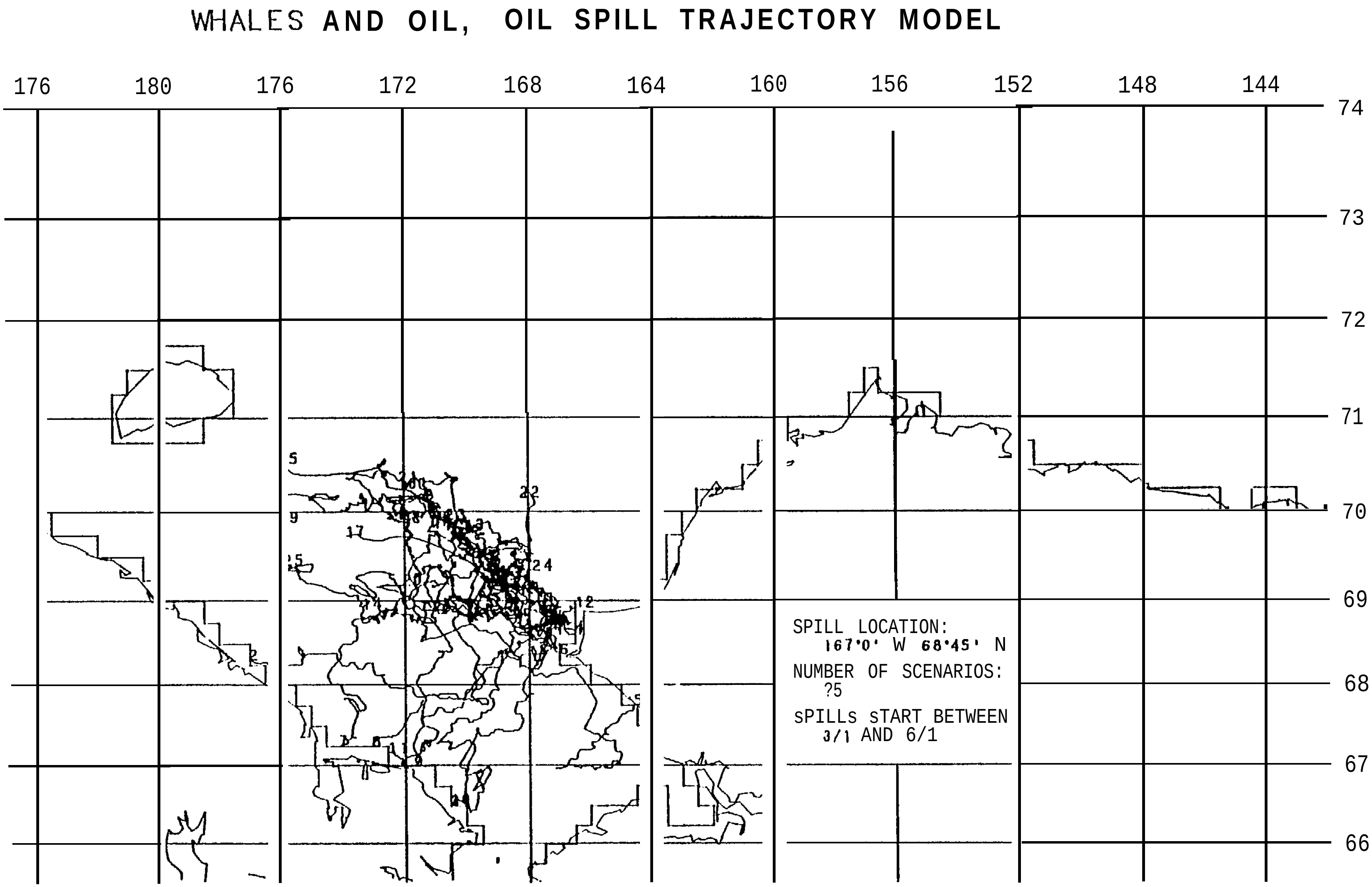



Figure 8–19. Twenty-five trajectories from Chukchi site 3 (167° W, 68° 45′ N), beginning between March 1 and June 1.

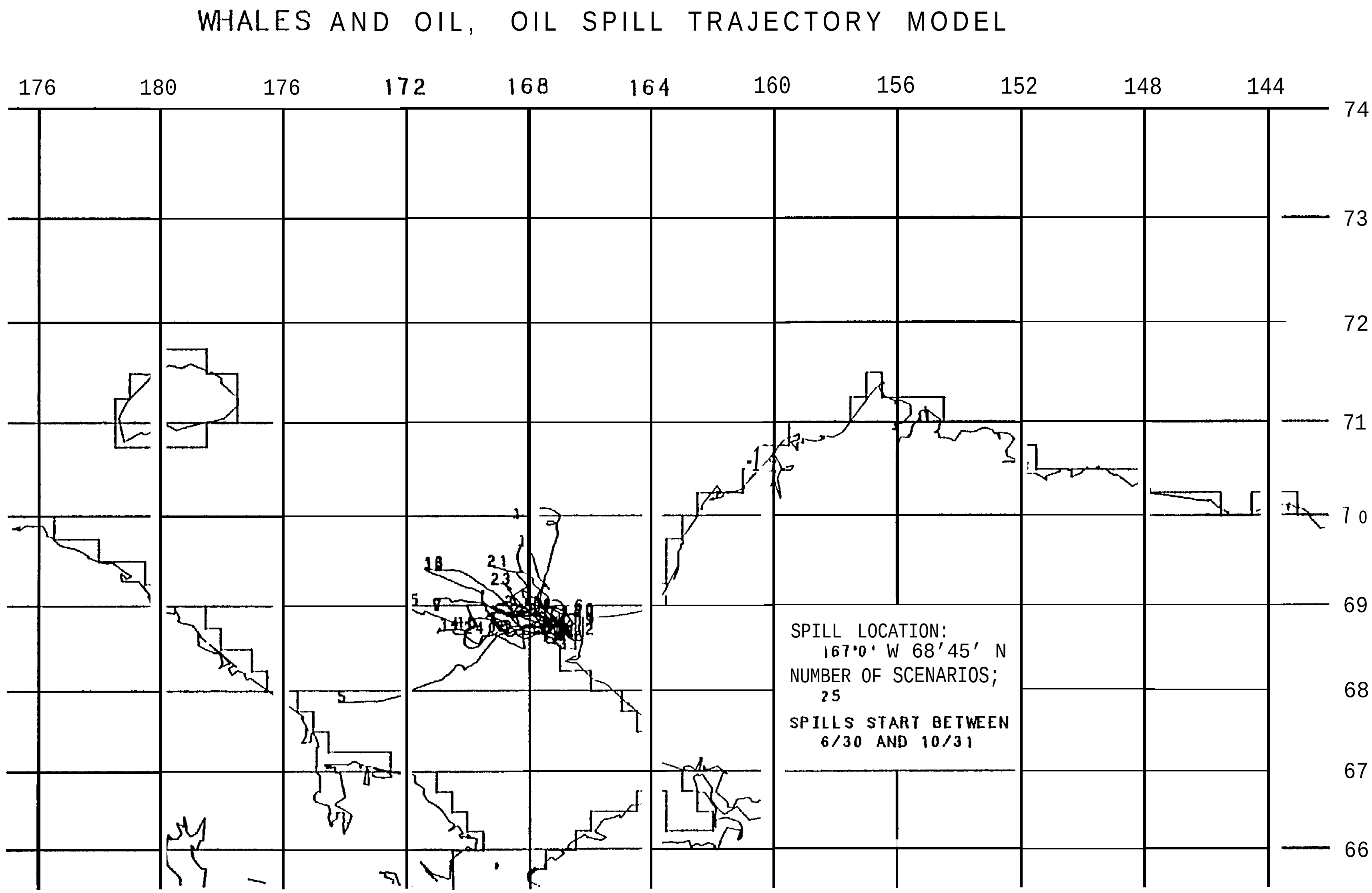



Figure 8-20. Twenty-five trajectories from Chukchi site 3 (167° W, 68° 45′ N), beginning between June 30 and October 31.

WHALES AND OIL, OIL SPILL TRAJECTORY MODEL

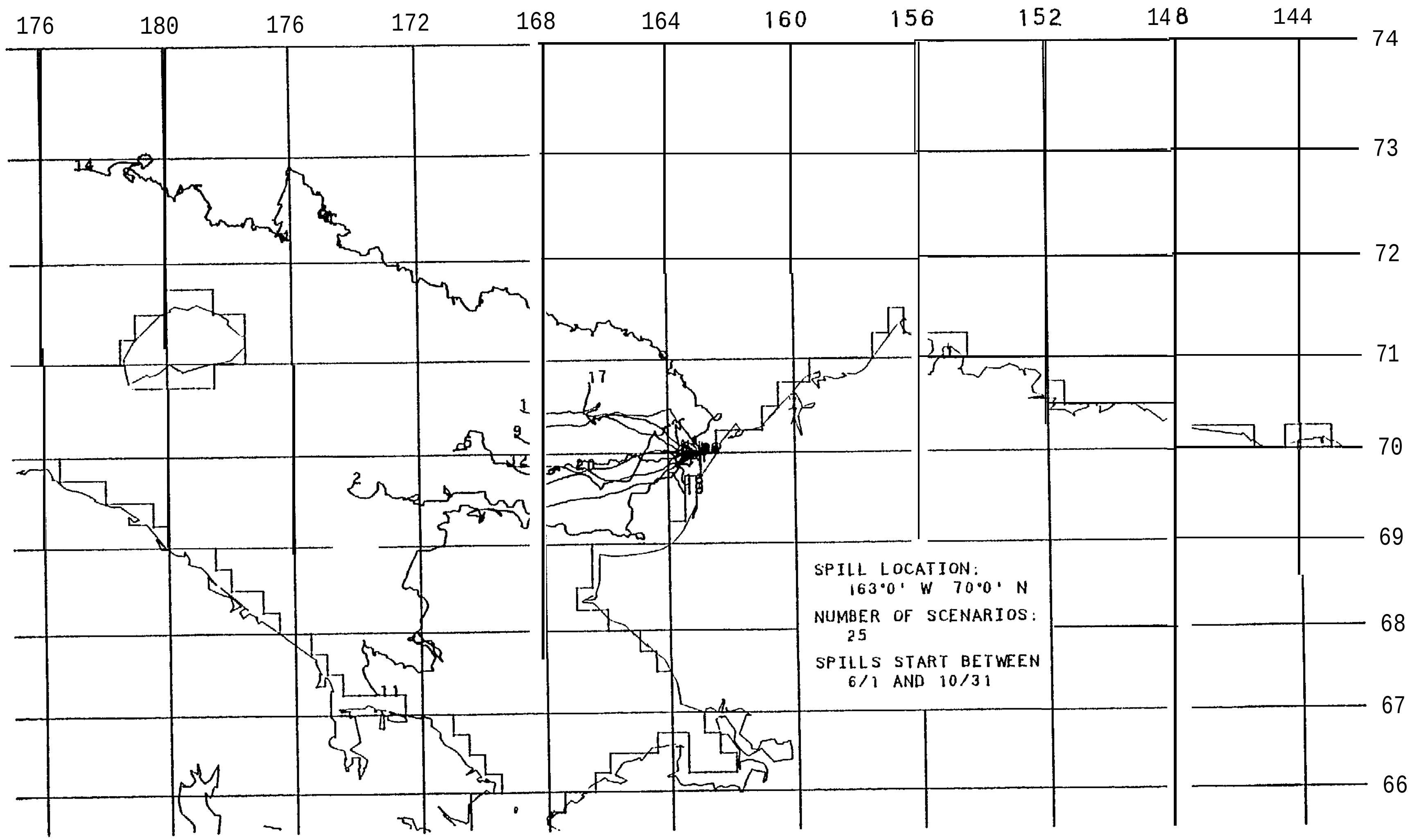



Figure 8-21. Twenty-five trajectories from Chukchi site 4 (163° W, 70° N), beginning between June 1 and October 31.

WHALES AND OIL, OIL SPILL TRAJECTORY MODEL

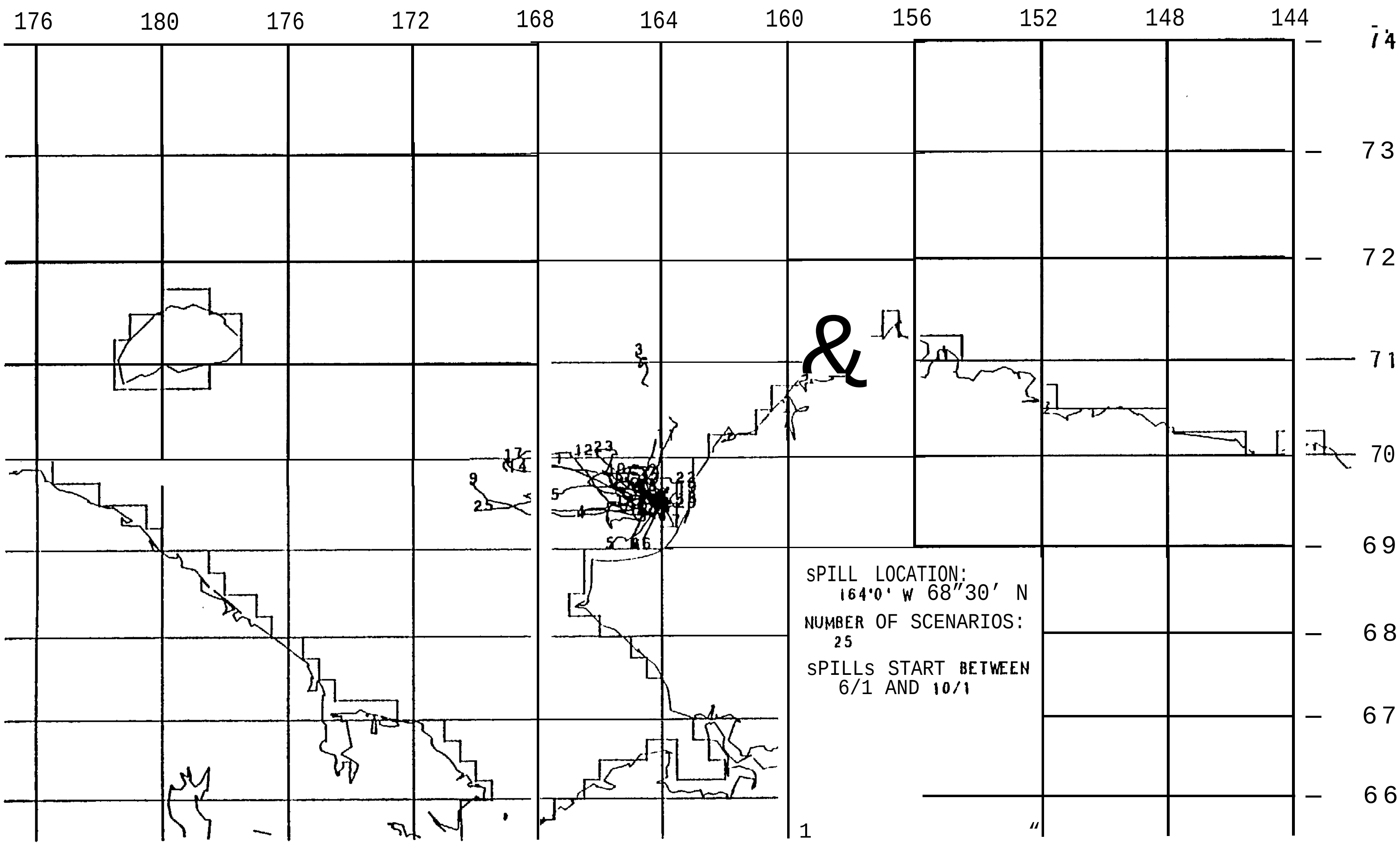



Figure 8-22. Twenty-five trajectories from Chukchi site 5 (164° W, 69° 30′ N), beginning between June 1 and October 1.

# WHALES AND OIL, OIL SPILL TRAJECTORY MODEL

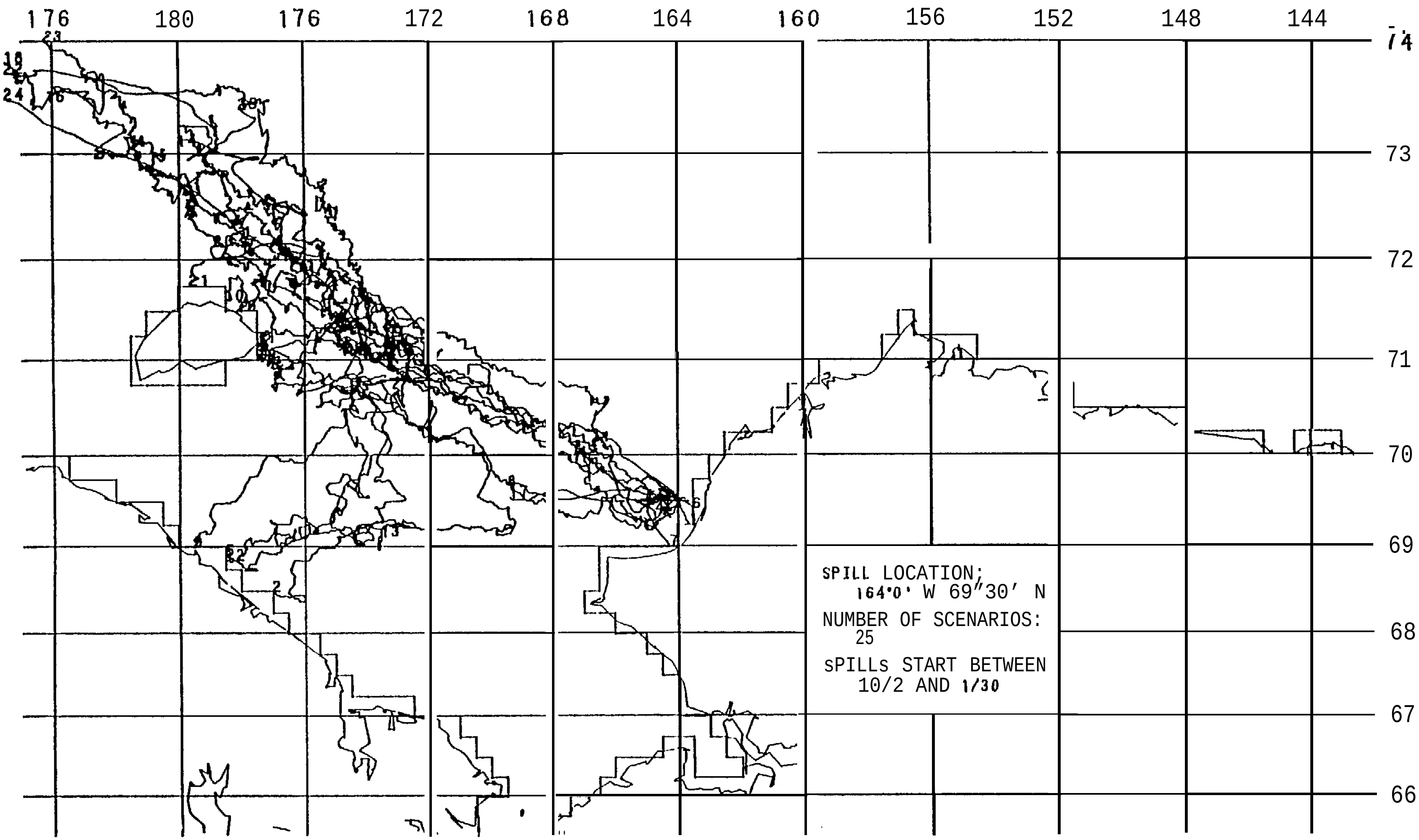



Figure 8-23. Twenty-five trajectories from Chukchi site 5 (164° W, 69° 30′ N), beginning between October 2 and January 30.

Table 8-13. Summary statistics by Chukchi Sea spill location of the number of bowhead whale-oil encounters by percent of the population.*

a. 3-Day Results

| Spill Sits | Spill Season | Number of bowhead whale surfacings in oil: 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | 501-600 | 601-700 | 701-800 | >800 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Apr 1-Jun 1 | 99.5 | 0.4 | 0.1 | + | | | | + | | |
| 1 | Jun 30-Ott 31 | 99.7 | 0.2 | 0.1 | + | | | | | | |
| 2 | Aug l-Ott 31 | 99.8 | 0.2 | 0.1 | + | | | | | | |
| 3 | Mar 1-Jun 1 | 98.5 | 1.0 | 0.4 | 0.1 | + | + | + | | | |
| 3 | Jun 30-Ott 31 | 100.0 | | | | | | | | | |
| 4 | Jun l-Ott 31 | 100.0 | + | | | | | | | | |
| 5 | Jun l-Ott 1 | 100.0 | | | | | | | | | |
| 5 | Ott 2-Jan 30 | 99.9 | 0.1 | + | | | | | | | |

b. 10-Day Results

| Spill Site | Spill Season | Number of bowhead whale surfacings in oil: 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | 501-600 | 601-700 | 701-800 | >800 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Apr 1-Jun 1 | 99.4 | 0.4 | 0.1 | + | + | | | + | | |
| 1 | Jun 30-Ott 31 | 99.4 | 0.5 | 0.2 | + | | | | | | |
| 2 | Aug l-Ott 31 | 99.7 | 0.2 | 0.1 | + | | | | | | |
| 3 | Mar 1-Jun 1 | 98.5 | 0,8 | 0.5 | 0.1 | + | + | + | | | |
| 3 | Jun 30-Ott 31 | 100.0 | | | | | | | | | |
| 4 | Jun l-Ott 31 | 99.8 | 0.1 | 0.1 | | | | | | | |
| 5 | Jun l-Ott 1 | 100.0 | | | | | | | | | |
| 5 | Ott 2-Jan 30 | 99.9 | 0.1 | + | + | | | | | | |

*Results are presented to nearest 0.1% A "+" designates a value greater than 0.0 but less than 0.1%.

Table 8-14. Summary statistics by Chukchi Sea spill location of the number of bowhead whale surfacings in oil as a percent of the total number of surfacings occurring while oil is present.

a. 3-Day Results

Number of bowhead whale surfacings in oil

| spill Site | Spill Season | 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | ≥500 |
|---|---|---|---|---|---|---|---|---|
| 1 | Apr 1-Jun 1 | 99.9965 | 0.0026 | 0.0007 | 0.0001 | | | 0,0001 |
| 1 | Jun 30-Ott 31 | 99.9978 | 0.0014 | 0.0007 | 0.0001 | | | |
| 2 | Aug l-Ott 31 | 99.9985 | 0.0009 | 0.0004 | 0.0001 | | | |
| 3 | Mar 1-Jun 1 | 99.9873 | 0.0079 | 0.0032 | 0.0010 | 0.0003 | 0.0002 | 0.0001 |
| 3 | Jun 30-Ott 31 | 100.0 | | | | | | |
| 4 | Jun l-Ott 31 | 99.9998 | 0.0001 | | | | | |
| 5 | Jun l-Ott 1 | 100.0 | | | | | | |
| 5 | Ott 2-Jan 30 | 99.9994 | 0.0005 | | | | | |

b. 10-Day Results

Number of bowhead whale surfacings in oil

| Spill Site | Spill Season | 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | >500 |
|---|---|---|---|---|---|---|---|---|
| 1 | Apr 1-Jun 1 | 99.9979 | 0.0015 | 0.0004 | 0.0001 | 0.0001 | | |
| 1 | Jun 30-Ott 31 | 99.9979 | 0.0015 | 0.0005 | 0.0001 | | | |
| 2 | Aug l-Ott 31 | 99.9990 | 0.0007 | 0.0002 | | | | |
| 3 | Mar 1-Jun 1 | 99.9930 | 0.0038 | 0.0024 | 0.0004 | 0.0002 | | |
| 3 | Jun 30-Ott 31 | 100.0 | | | | | | |
| 4 | Jun l-Ott 31 | 99.9995 | 0.0003 | 0.0002 | | | | |
| 5 | Jun l-Ott 1 | 100.0 | | | | | | |
| 5 | Ott 2-Jan 30 | 99.9996 | 0.0003 | 0,0001 | | | | |

Table 8-15. Summary statistics by Chukchi Sea spill location of the number of gray whale-oil encounters by percent of the population.*

a. 3-Day Results

| Spill Site | Spill Season | Number of gray whale surfacings in oil: 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | >500 |
|---|---|---|---|---|---|---|---|---|
| 1 | Apr 1-Jun 1 | 100.0 | | | | | | |
| 1 | Jun 30-Ott 31 | 99.5 | 0.4 | 0.1 | + | | + | |
| 2 | Aug l-Ott 31 | 100.0 | | | | | | |
| 3 | Mar 1-Jun 1 | 99.9 | 0.1 | + | | + | | |
| 3 | Jun 30-Ott 31 | 99.3 | 0.5 | 0.1 | + | | | |
| 4 | Jun l-Ott 31 | 99.6 | 0.3 | 0.1 | + | + | | |
| 5 | Jun l-Ott 1 | 99.2 | 0.6 | 0.1 | 0.1 | + | | |
| 5 | Ott 2-Jan 30 | 99.7 | 0.2 | 0.1 | | | | |

b. 10-Day Results

| Spill Site | Spill Season | Number of gray whale surfacings in oil: 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | >500 |
|---|---|---|---|---|---|---|---|---|
| 1 | Apr 1-Jun 1 | 100.0 | | | | | | |
| 1 | Jun 30-Ott 31 | 99.3 | 0.5 | 0.2 | + | + | + | + |
| 2 | Aug l-Ott 31 | 100.0 | | | | | | |
| 3 | Mar 1-Jun 1 | 99.8 | 0.2 | + | | | + | |
| 3 | Jun 30-Ott 31 | 99.2 | 0.6 | 0.2 | + | | + | |
| 4 | Jun l-Ott 31 | 99.2 | 0.5 | 0.2 | 0.1 | + | | |
| 5 | Jun l-Ott 1 | 98.6 | 0.9 | 0.3 | 0.1 | + | + | |
| 5 | Ott 2-Jan 30 | 99.7 | 0.1 | 0.1 | + | | | |

*Results are presented to nearest 0.1%. A "+" designates a value greater than 0.0 but less than 0.1%.

sites affect less than 1% of the population. As has been described previously, the number of surfacings occurring in oil represent an extremely small fraction of the total number of surfacings occurring while oil is present (Table 8-16).

The results presented above assume the spill scenarios simulated are representative of actual conditions which might occur, and that the modeled bowhead and gray whale distributions are representative of the population distributions. For bowhead whales, density observations used for model calibration are available in the Chukchi Sea only for the period April - May. In general the model is able to reproduce observed bowhead densities within one standard deviation of the observed mean. Simulated densities are higher than observed in the area offshore of Pt. Hope, although simulated densities agree well with observations to the north and south. Since density observations are not available for the autumn migration across the Chukchi Sea, the migration model relies on sighting data and hypothesized routes to simulate bowhead whale movements.

Gray whales are present in the Chukchi Sea from July through early November. Simulated whale densities in July agree well with observations for the eastern Chukchi Sea. In the southern Chukchi Sea near the Bering Strait simulated densities are much higher than observed. Only spring spills from site 3 move into this region, so only estimates of gray whale-oil encounters for site 3 spring spills are likely to be high. Density estimates are not available in the Chukchi Sea for the other months of interest.

## 8.4 St. George Basin

The 5 sites in St. George Basin selected by MMS for investigation of oil spill impacts on bowhead and gray whales are shown in Figure 8-24. Site 1 is located in Unimak Pass; site 5 is near the Pribilof Islands. The spill locations, sizes and season(s) over which the spills occur are given in Table 8-17. Spills at sites 1 and 4 are considered over 2 seasons. Trajectories for the 25 spill scenarios simulated for each site and season are shown in Figures 8-25 through 8-31.

Table 8-17. Specification of hypothetical spills in the St. George Basin planning area.

| Spill Site | Spill Location Longitude (W) | Spill Location Latitude (N) | Season | Spill Volume (bbls) | Release Rate (bbls/day) |
|---|---|---|---|---|---|
| 1 | 165° | 54° 15′ | Mar 1 - Jun 30 | 10,000 | 2,000 |
| 1 | 165° | 54° 15′ | Aug 1 - Dec 31 | 10,000 | 2,000 |
| 2 | 168° | 56° | May 1 - Ott 31 | 10,000 | 2,000 |
| 3 | 167° | 55° 30′ | May 1 - Ott 31 | 10,000 | 2,000 |
| 4 | 168° | 53° 45′ | May 1 - Ott 31 | 10,000 | 2,000 |
| 4 | 168° | 53° 45′ | Nov 1 - May 31 | 10,000 | 2,000 |
| 5 | 170° | 56° 40′ | Apr 1 - Nov 30 | 10,000 | 2,000 |

Table 8-16. Summary statistics by Chukchi Sea spill location of the number of gray whale surfacings in oil as a percent of the total number of surfacings occurring while oil is present.

a. 3-Day Results

| Spill Site | Spill Season | Number of gray whale surfacings in oil: 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | >500 |
|---|---|---|---|---|---|---|---|---|
| 1 | Apr 1-Jun 1 | 100.0 | | | | | | |
| 1 | Jun 30-Ott 31 | 99.9950 | 0.0039 | 0.0008 | 0.0002 | | 0.0001 | |
| 2 | Aug l-Ott 31 | 100.0 | | | | | | |
| 3 | Mar 1-Jun 1 | 99.9988 | 0.0009 | 0.0003 | | 0.0001 | | |
| 3 | Jun 30-Ott 31 | 99.9935 | 0.0050 | 0.0013 | 0.0001 | | | |
| 4 | Jun l-Ott 31 | 99.9948 | 0.0036 | 0.0010 | 0.0005 | 0.0001 | | |
| 5 | Jun l-Ott 1 | 99.9913 | 0.0063 | 0.0016 | 0.0007 | 0.0001 | | |
| 5 | Ott 2-Jan 30 | 99.9969 | 0.0020 | 0.0010 | 0.0001 | 0.0001 | | |

b. 10-Day Results

| Spill Site | Spill Season | Number of gray whale surfacings in oil: 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | >500 |
|---|---|---|---|---|---|---|---|---|
| 1 | Apr 1-Jun 1 | 100.0 | | | | | | |
| 1 | Jun 30-Ott 31 | 99.9953 | 0.0033 | 0.0010 | 0.0002 | 0.0001 | 0.0001 | 0.0001 |
| 2 | Aug l-Ott 31 | 100.0 | | | | | | |
| 3 | Mar 1-Jun 1 | 99.9990 | 0.0008 | 0.0002 | | | | |
| 3 | Jun 30-Ott 31 | 99.9960 | 0.0031 | 0.0008 | 0.0001 | | | |
| 4 | Jun l-Ott 31 | 99.9942 | 0.0037 | 0.0013 | 0.0004 | 0.0003 | | |
| 5 | Jun l-Ott 1 | 99.9900 | 0.0064 | 0.0023 | 0.0009 | 0.0004 | 0.0001 | |
| 5 | Ott 2-Jan 30 | 99.9980 | 0.0011 | 0.0007 | 0.0001 | | 0.0001 | |

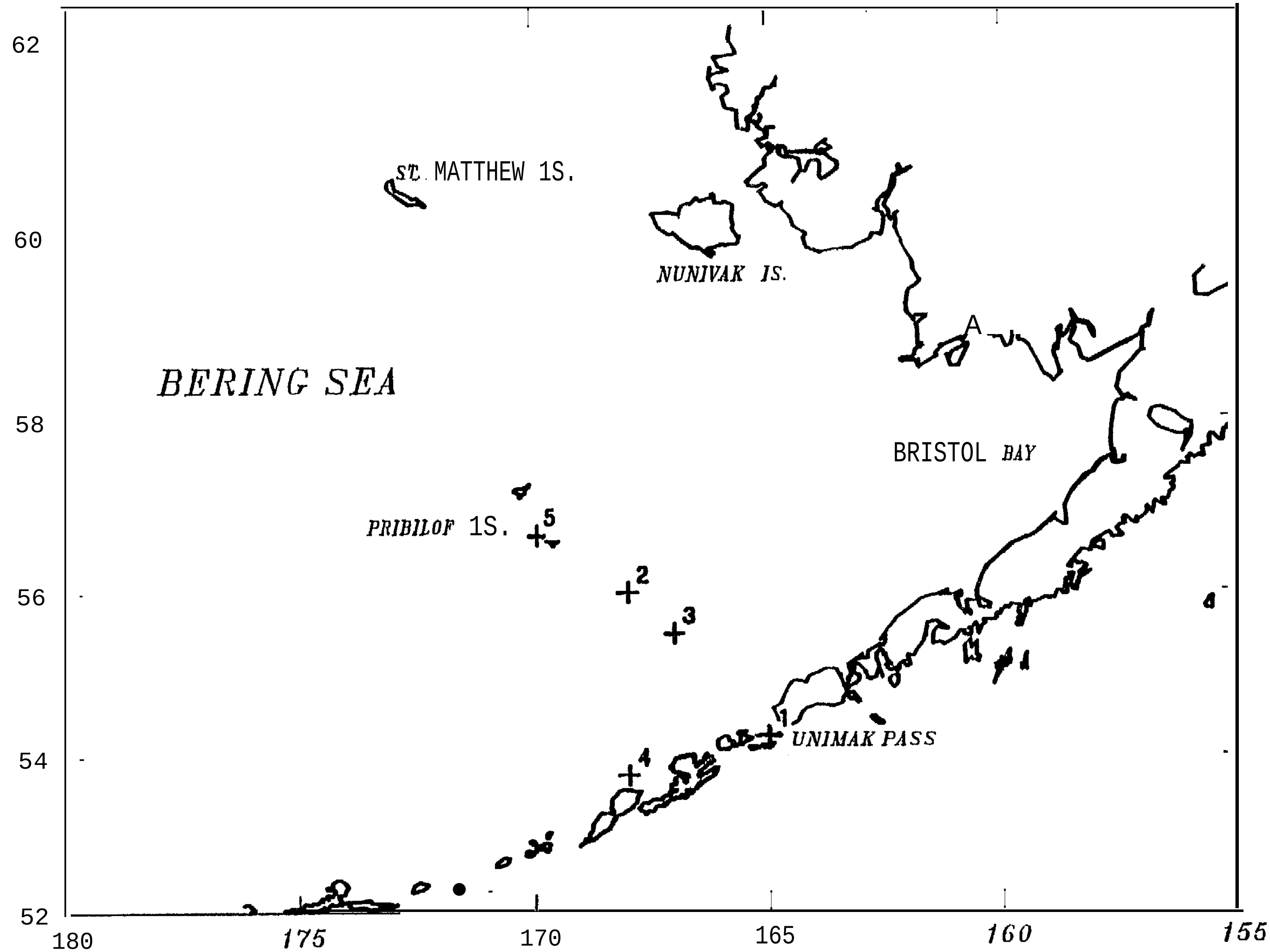



Figure 8-24, Location of the St. George Basin planning area oil spill release sites.

## WHALES AND OIL, GIL SPILL TRAJECTORY MODEL

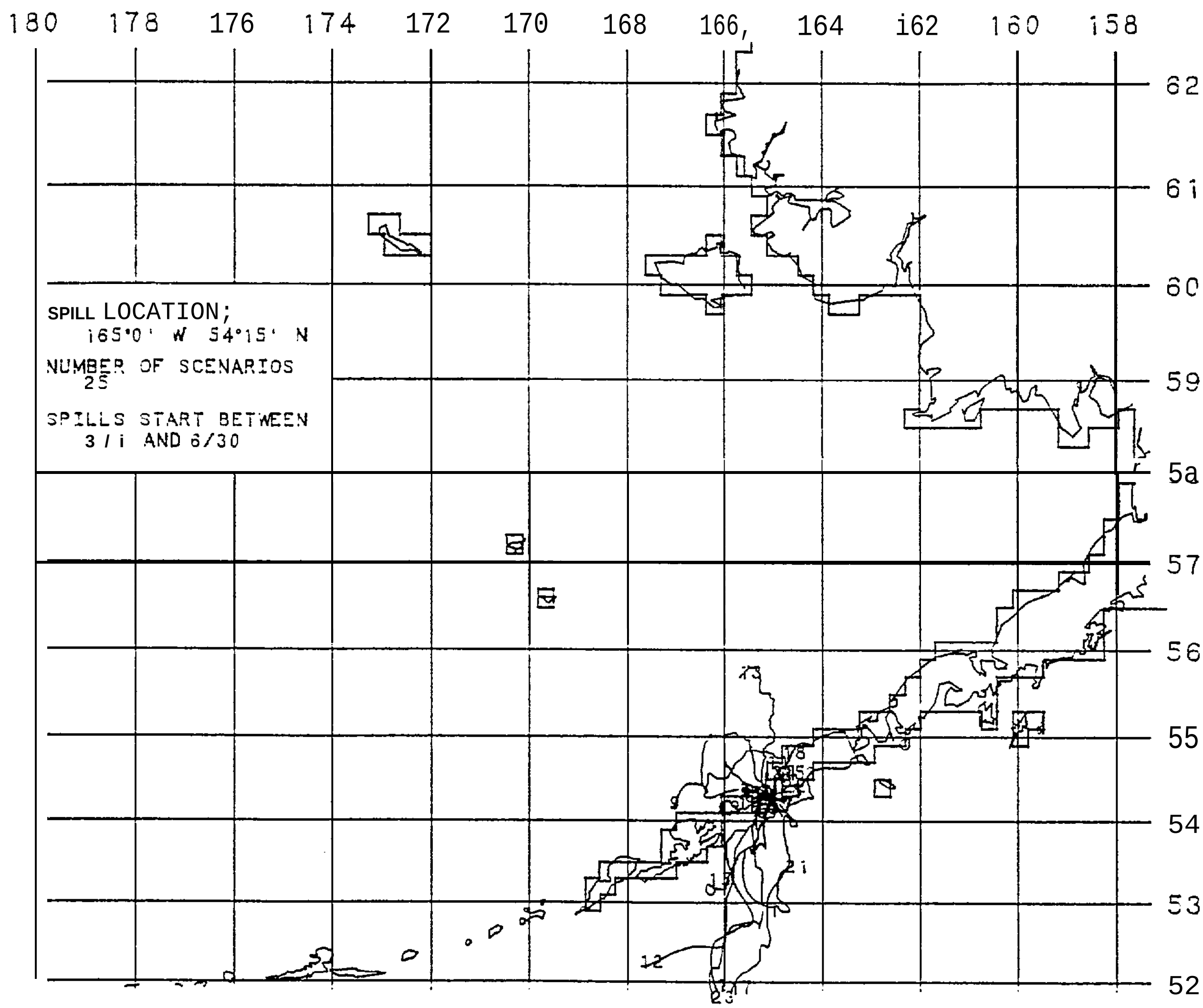



Figure 8-25. Twenty-five trajectories from St. George site 1 (165° W, 54° 15' N), beginning between March 1 and June 30.

WHALES **AND OIL, OIL SPILL TRAJECTORY MODEL**

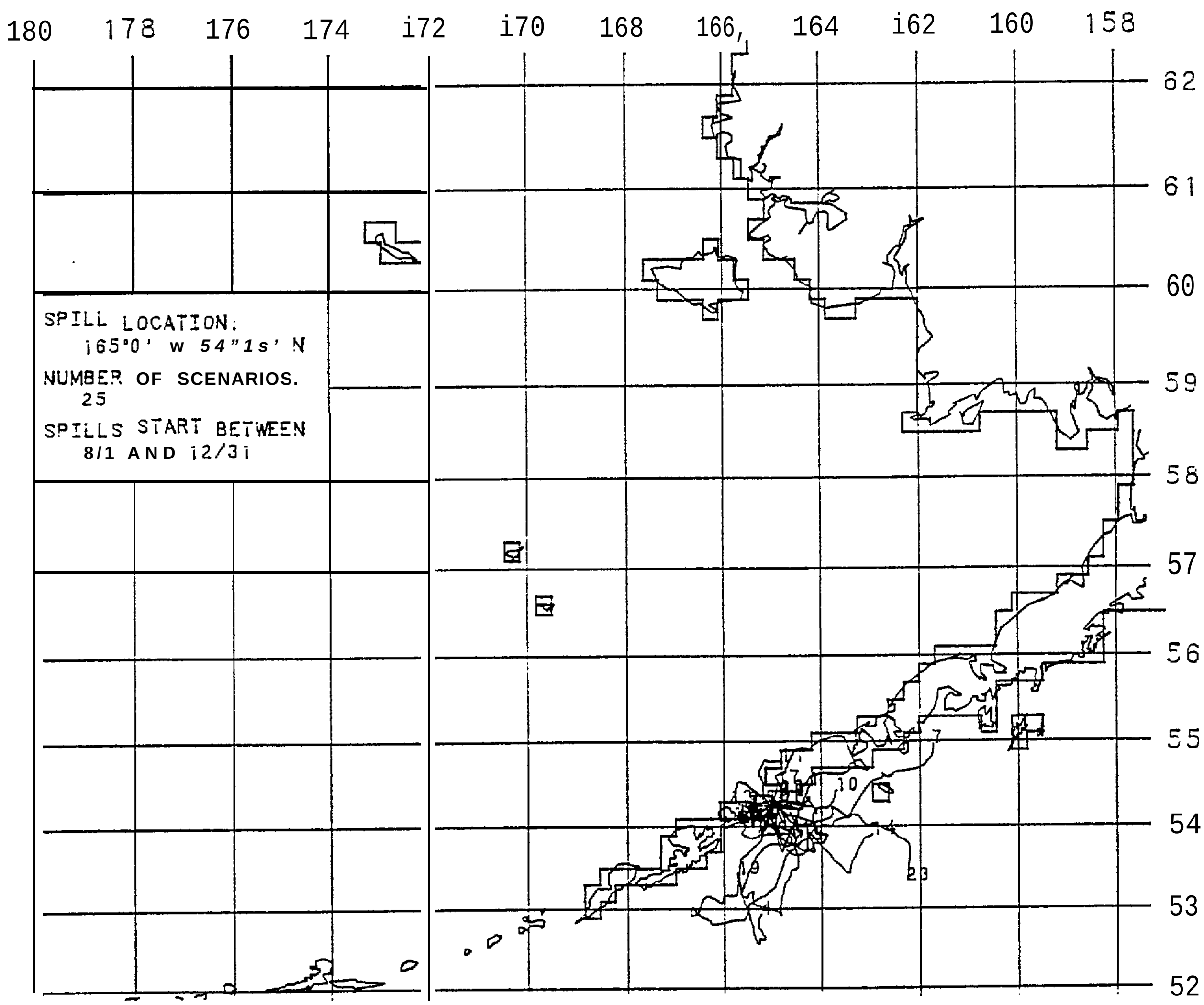



Figure 8-26. Twenty-five trajectories from St. George site 1 (165° W, 54° 15' N), beginning between August 1 and December 31.

WHALES AND OIL, GIL SPILL TRAJECTORY MODEL

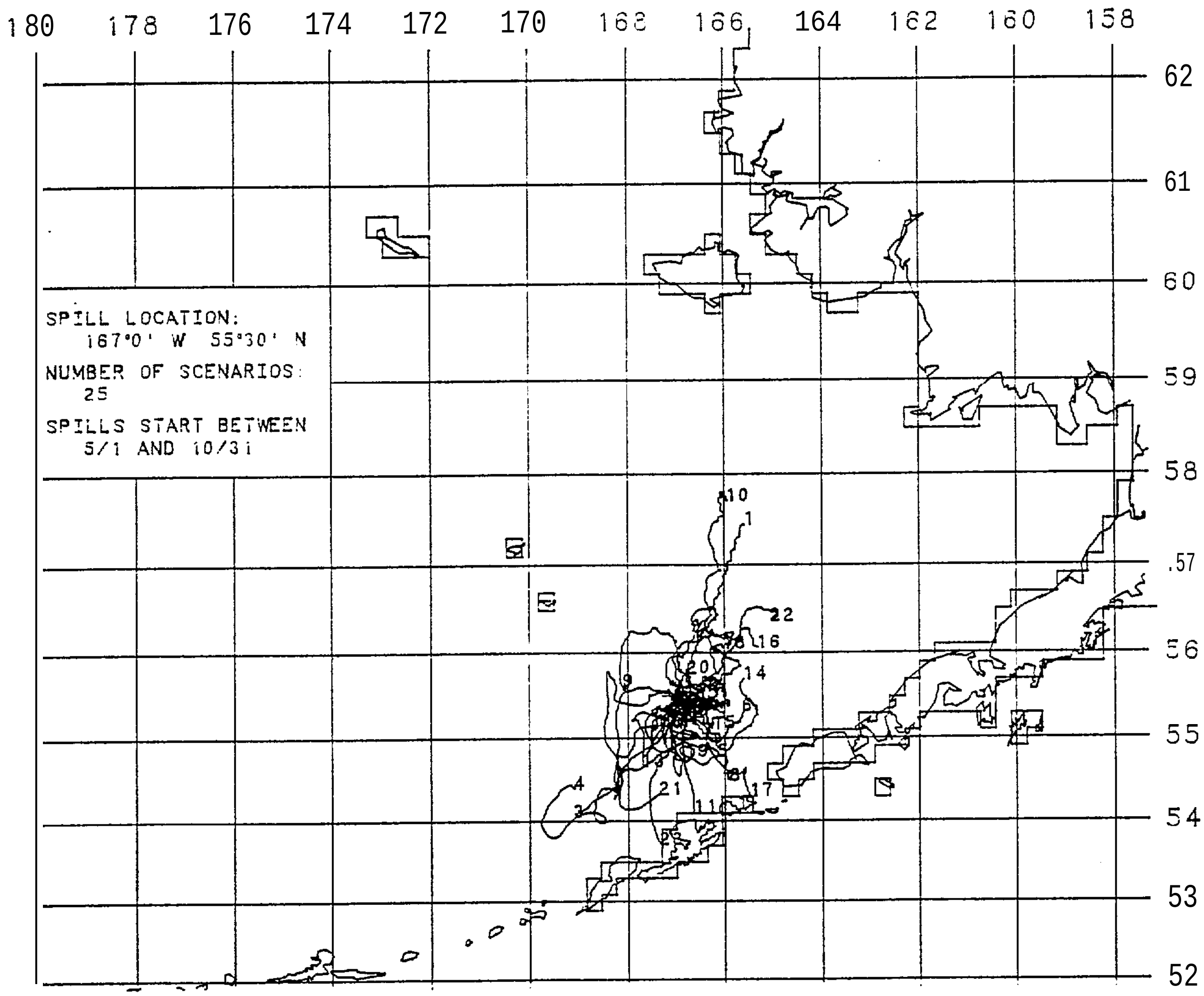



Figure 8-28, Twenty-five trajectories from St. George site 3 (167° W, 55° 30' N), beginning between May 1 and October 31.

## WHALES AND OIL, OIL SPILL TRAJECTORY MODEL

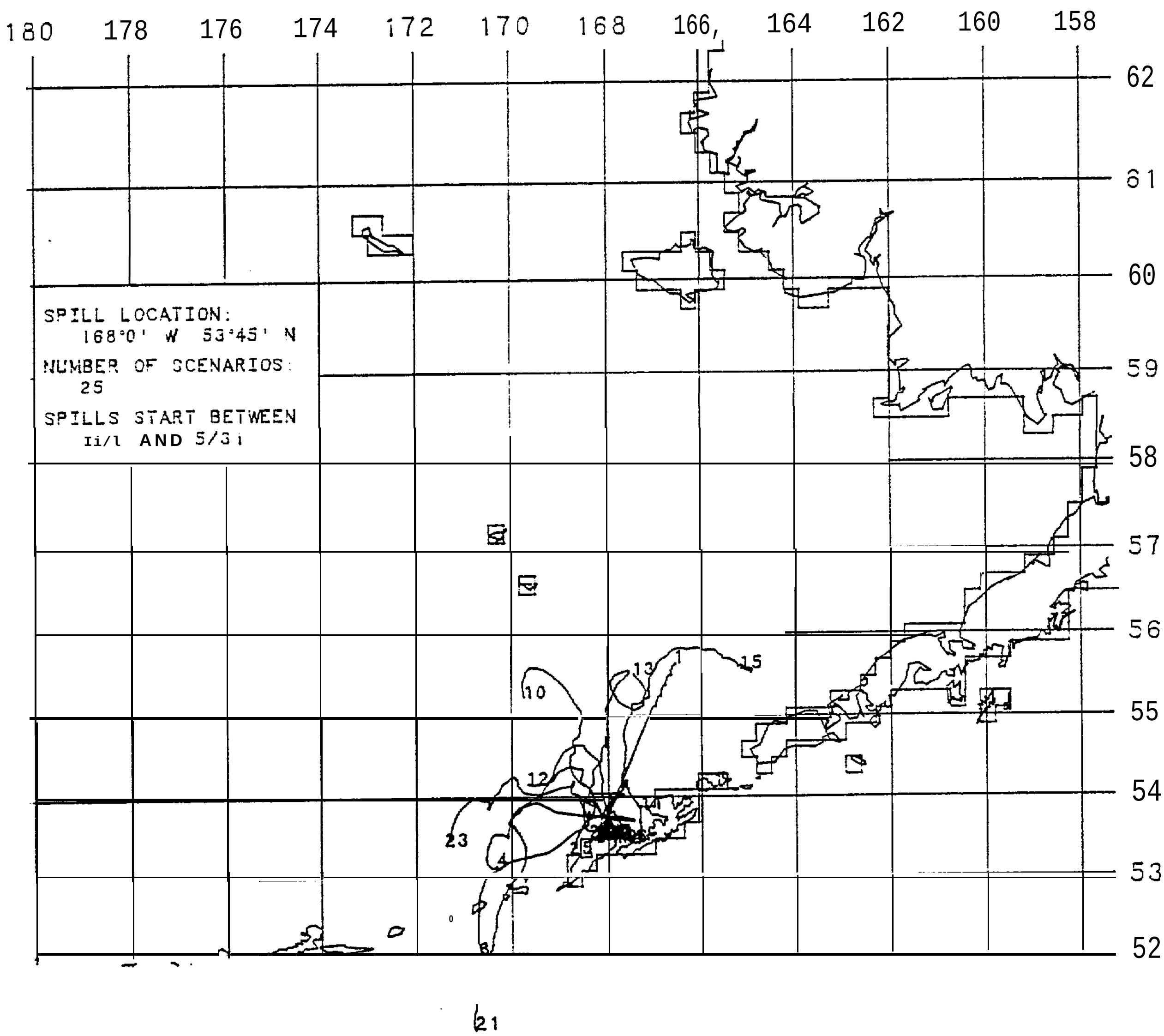



Figure 8-30. Twenty-five trajectories from St. George site 4 (168° W, 53° 45' N), beginning between November 1 and May 31.

WHALES AND OIL, GIL SPILL TRAJECTORY MODEL

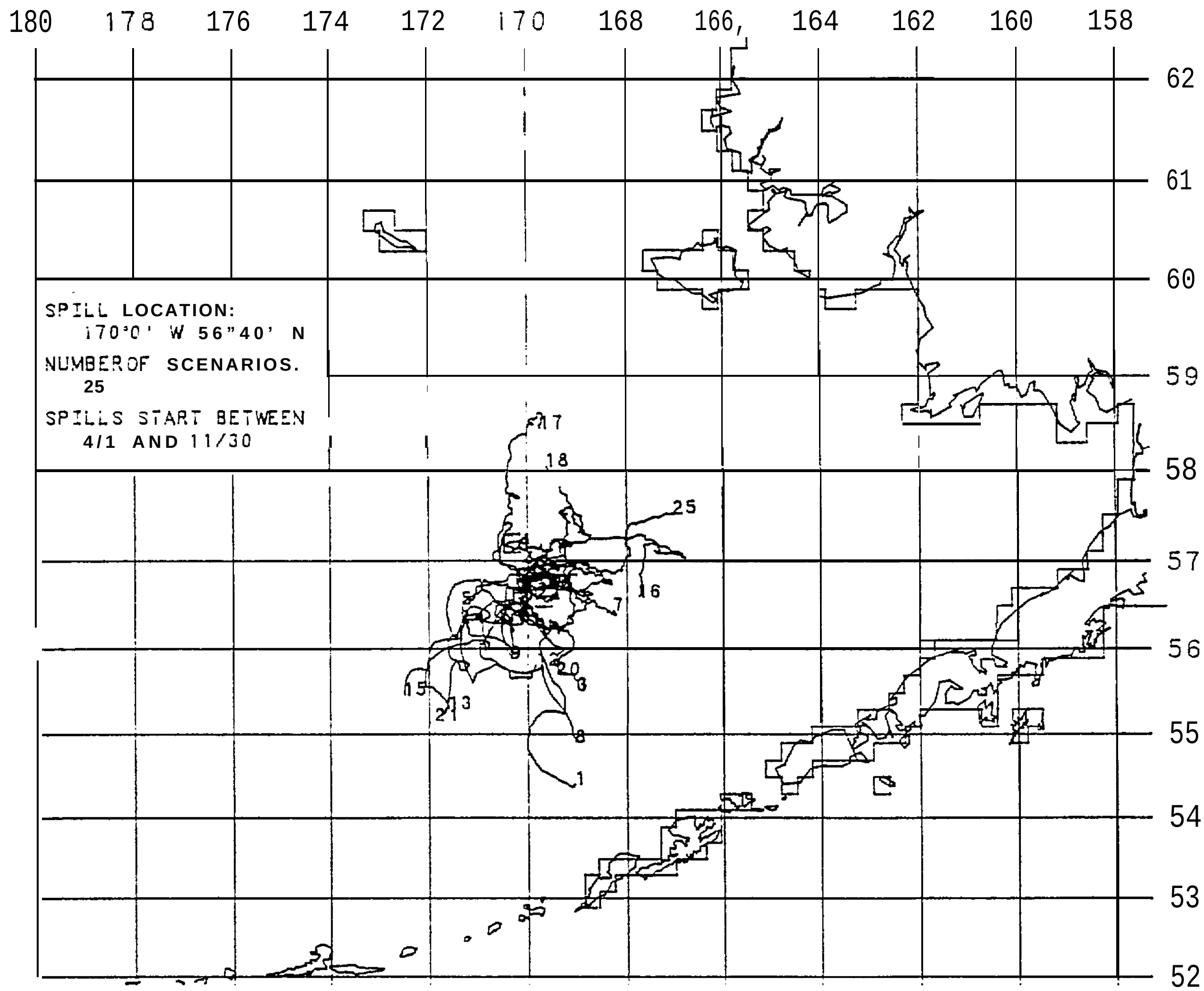



Figure 8-31. Twenty-five trajectories from St. George site 5 (170° W, 56° 40' N), beginning between April 1 and November 30.

Bowhead whales are not typically present in St. George Basin at any time of year. The migration model simulates bowhead whales wintering south of St. Matthew Island but these whales do not extend far enough south to be in any danger of encountering oil spilled at the hypothetical St. George sites. In heavy ice years bowhead whales have been observed in the southern Bering Sea (Braham et al, 1984). However these sightings are not thought to be representative of bowhead whale behavior and are not represented in the model. Therefore no simulations were run to compare bowhead whale movements with the trajectories of spilled oil.

Virtually the entire gray whale population utilizes Unimak Pass to enter the Bering Sea in April, May and early June and to leave in November and December. A spill in Unimak Pass during one of these periods of heavy usage could impact large numbers of gray whales. Once in the Bering Sea gray whales remain close to the coastline as they migrate around Bristol Bay to Nunivak Island. From here they head for St. Lawrence Island before dispersing to various feeding areas to the north. Although a small number of whales have been observed to travel to the Pribilof Islands (Braham, 1984), this portion of the population is thought to be very small and is not represented in the migration model. In the fall, gray whales return to Unimak Pass following a broad path across the eastern Bering Sea. These migration patterns keep the gray whales outside the areas impacted by oil spilled at sites 2, 3, 4 and 5.

The number of simulations resulting in whale-oil encounters for each of the 5 sites is given in Table 8-18. Appendix D presents the number of times each simulated whale point encountered oil for those spill scenarios which resulted in whale-oil encounters.

Table 8-18. Number of spill scenarios resulting in whale-oil encounters for each site and season in the St. George Basin planning area.

| | | Number of scenarios (out of 25) resulting in whale-oil encounters | |
|---|---|---|---|
| Spill Site | Season | Bowhead | Gray |
| 1 | Mar 1 - Jun 30 | 0 | 12 |
| 1 | Aug 1 - Dec 31 | 0 | 7 |
| 2 | May 1 - Ott 31 | 0 | 0 |
| 3 | May 1 - Oct 31 | 0 | 0 |
| 4 | May 1 - Ott 31 | 0 | 0 |
| 4 | Nov 1 - May 31 | 0 | 0 |
| 5 | Apr 1 - Nov 30 | 0 | 0 |

The results of the gray whale simulations are given in Table 8-19 and 8-20. For a spring spill in Unimak Pass (site 1) an average of 3.5% of the population will encounter oil. A winter spill in Unimak Pass results in an average of 2.9% of the population encountering oil. The surfacings occurring in oil represent less than 0.1% of all surfacings occurring over the spill duration in both seasons (Table 8-20). Spills at the other St. George Basin sites had no impact on gray whales.

The probability of gray whales being oiled by spills in the St. George Basin planning area is relatively low. Of the 5 sites for which spill scenarios were generated, only spills at site 1 located in Unimak Pass resulted in whale-oil encounters. A spill in Unimak Pass will only endanger gray whales if its timing coincides with the migration of whales through the Pass, in April - May or November - December. The migration model is able to replicate the observed timing and distribution of gray whales as they enter and exit the Bering Sea (see Section 2.3), minimizing the uncertainty in the above estimates. It must be noted that modeled gray whale migrations begin and end just south of Unimak Pass, so no whale-oil encounters can be calculated for spills which move south out of the Pass. The movements of gray whales across Bristol Bay and the southern Bering Sea are not well known as the whales migrate south in the autumn. The hypothesized route keeps the whales to the east of the simulated spills, and results in no whale-oil encounters.

Table 8-19. Summary statistics by St. George spill location of the number of gray whale-oil encounters by percent of the population.*

a. 3-Day Results

| | | Number of gray whale surfacings in oil | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Spill Site" | Spill Season | 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | >500 |
| 1 | Mar 1-Jun 30 | 98.1 | 0.6 | 0.8 | 0.4 | 0.1 | 0.1 | + |
| 1 | Aug l-Dee 31 | 99.1 | 0.5 | 0.2 | 0.1 | + | | + |
| 2 | May l-Ott 31 | 100.0 | | | | | | |
| 3 | May l-Ott 31 | 100.0 | | | | | | |
| 4 | May l-Ott 31 | 100.0 | | | | | | |
| 4 | Nov l-May 31 | 100.0 | | | | | | |
| 5 | Apr 1-Nov 30 | 100.0 | | | | | | |

b. 10-Day Results

| | | Number of gray whale surfacings in oil | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Spill Site | Spill Season | 0 | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | >500 |
| 1 | Mar 1-Jun 30 | 96.5 | 1.2 | 1.3 | 0.6 | 0.3 | 0.1 | + |
| 1 | Aug l-Dee 31 | 97.1 | 1.5 | 1.0 | 0.3 | + | | + |
| 2 | May l-Ott 31 | 100.0 | | | | | | |
| 3 | May l-Ott 31 | 100.0 | | | | | | |
| 4 | May l-Ott 31 | 100.0 | | | | | | |
| 4 | Nov l-May 31 | 100.0 | | | | | | |
| 5 | Apr 1-Nov 30 | 100.0 | | | | | | |

* Results are presented to the nearest 0.1%. A "+" designates a value greater than 0.0 but less than 0.1%.

## 9. Total Probabilities of Interactions: Example for the Beaufort Sea Planning Area

An estimate of the total whale-oil spill interaction probabilities in the Beaufort Sea is included here to demonstrate the methodology and the model capability. The results, however, are unreliable for the following reasons:

1. The array of potential spill sites and seasons must fully reflect the ranges actually expected to occur. The sites and seasons used here were selected because interactions with whales appeared likely at those times. Thus the results of the total probability computations overestimate actual probabilities of whale-oil interactions.

2. The oil spill probabilities which have been used here (MMS, 1986) are for spills greater than 1000 barrels. The volumes of simulated spills should therefore be selected from an appropriate probability distribution (e.g., Lanfear and Amstutz, 1983). Due to funding limitations, fewer than 200 spills have been simulated in each planning area; for purposes of consistency and ease of intercomparison, only 10,000 barrel spills have been simulated. Although this is near the mean value for OCS platform spill sizes (Lanfear and Amstutz, 1983), we have demonstrated in Section 6 that the number of whale-oil interactions is not linear with spill volume. To avoid biasing results, a larger number of spills of random size should be simulated.

The total probability results given in this report are therefore only representative of the type of output available with the model system; the actual magnitudes of the results reported here are unreliable.

We compute total probabilities of whale-oil spill interactions as follows. Let $A_i$ represent the event that i oil spills occur, and $B_j$ represent the event tht j whales interact with oil spills. The definition of conditional probability states that

$$P(A_i \cap B_j) = P(B_j/A_i) \cdot P(A_i)$$

In words, the probability that i oil spills occur and j whales encounter oil is equal to the probability that j whales encounter oil given that i oil spills recur multiplied by the probability that i oil spills actually do occur. In the present case, we have $P(A_i)$ given as a Poisson process with known parameters (MMS, 1986), as shown in Table 9-1. These probability estimates are based on a combination of platform, tanker, and pipeline sources, variable by lease area, and probabilities of spills associated with each source type (Lanfear and Amstutz, 1983).

Table 9-1. Estimated number of oil spills exceeding 1000 barrels and the probability of one or more spills (from MMS, 1986).

| Planning Area | Conditional oil resources ($10^6$ bbl) | Mean Number of spills expected | Probability of 1 or more spills |
|---|---|---|---|
| Navarin | 1920 | 5.38 | 0.99+ |
| Beaufort | 627 | 1.63 | 0.80 |
| Chukchi | 1152 | 2.99 | 0.95 |
| St. George | 135 | 0.53 | 0.41 |

If we assume that all spill scenarios from all sites are equally likely, then we can draw at random from the "universe" of oil spill - whale interaction scenarios created for the lease sale or planning area to create a large number of groups of i spills. In other words, if we want to create groups of 12 spills from a total of 125 different individual scenarios, there are $125!/(12!\ 113!) \approx 10^{14}$ different combinations available. We then create a large subspace of 20,000 of these combinations of i oil spill - whale interaction events. From this subspace, we can compute $P(B_j/A_i)$ for each value of i (i.e., successively larger numbers of oil spills occurring). The total probability that j whales will encounter oil is then

$$P(B_j) = \sum_{i=1}^{\infty} P(B_j/A_i) \cdot P(A_i)$$

In practice, we do not need to go to an infinite, nor even a very large number of spills, since the associated probabilities of occurrence rapidly become neglible.

This analysis assumes the scenarios simulated form a representative sample of the actual range of oil spill events which may reasonably be expected to occur, and that spills are equally likely to occur at each of the sites and seasons investigated. This latter assumption could be amended to account for variations in probability of occurrence among sites and seasons by applying appropriate weighting factors during the random sampling procedure.

The process described above is applied to the simulations for each species. Three separate analyses are performed on the data to determine the total probability of 1) whales encountering oil, 2) the number of whale-oil interactions and 3) the percent of total surfacings occurring in oil.

To compute the total probability of whales encountering oil spilled in the Beaufort Sea planning area, the probabilities of 0, 1, 2, . . . 8 spills occurring were considered. The probability of at least 1 spill exceeding 1000 barrels occurring in the Beaufort Sea planning area is 0.804 (MMS, 1986). The mean number of spills expected to occur is 1.63 (Table 9-l). The cumulative Poisson probability of 0-8 spills is 0.9999; the probability of more than 8 spills occurring is therefore very small and is neglected here. The numbers of whales encountering oil for the 175 spill scenarios (25 spills from 5 sites, 2 sites with 2 seasons) were used to generate the number of whales encountering oil for 2, 3, 4, . . . 8 spills occurring, as described for the general case above.

For bowhead whales, the total probability of at least 1 whale encountering oil spilled in the Beaufort Sea planning area is 56.8% (Figure 9-l). Although the mean number of expected spills is only 1.63, every site and season for which spill scenarios were simulated resulted in whale-oil encounters. This results in a greater than 50% probability that bowhead whales will encounter oil.

The total probability distribution for the number of bowhead whale surfacings in oil is given in Figure 9-2. Again there is a 56.8% probability of at least 1 whale-oil encounter and a 43.2% probability of no whales surfacing in oil. The number of surfacings occurring in oil as a fraction of the total number of surfacings occurring while oil is present gives a relative sense of the overall impact of the spilled oil. AS shown in Figure 9-3, there is greater than an 83% probability that 20 or fewer of every 100,000 surfacings will be in oil.

Gray whale simulations resulted in far fewer spill scenarios with whale-oil encounters than the bowhead whale simulations. Accordingly, the total probability of gray whales encountering oil is much less. Figure 9-4 shows a probability of 93.7% that no gray whales will encounter oil. There is a corresponding probability of 6.3% that at least 1 whale-oil encounter till occur (Figure 9-5). When the number of surfacings in oil is expressed as a fraction of the total number of surfacings occurring while oil is present, the total probability that 5 or fewer of every 100,000 surfacings will be in oil is 98.8% (Figure 9-6). This includes a 93.7% probability of no surfacings in oil.

| Number of Spills | Prob. of N Spills | Number of bowhead whales oiled if N spills occur: 0 | 1-200 | 201-400 | 401-600 | 601-800 | 801-1000 | 1001-1200 | 1201-1400 | 1401-1600 | >1600 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .1959 | .1959 | | | | | | | | | |
| 1 | .319.4 | .1551 | .1077 | .0310 | .0183 | .0018 | .0055 | | | | |
| 2 | .2603 | .0609 | .1060 | .0428 | .0301 | .0093 | .0087 | .0017 | .0005 | .0002 | .0001 |
| 3 | .1414 | .0160 | .0512 | .0288 | .0224 | .0108 | .0072 | .0028 | .0014 | .0006 | .0003 |
| 4 | .0576 | .0031 | .0170 | .0121 | .0106 | .0064 | .0043 | .0021 | .0012 | .0005 | .0004 |
| 5 | .0188 | .0005 | , 0041 | .0038 | .0037 | .0026 | .0018 | .0011 | .0006 | .0003 | .0003 |
| 6 | .0051 | .0001 | .0008 | .0009 | .0010 | .0008 | .0006 | .0004 | .0003 | .0001 | .0002 |
| 7 | .0012 | + | .0001 | .0002 | .0002 | .0002 | .0002 | .0001 | .0001 | + | .0001 |
| 8 | .0002 | + | + | + | i- | + | + | + | + | i- | |
| Total Probability | .9999 | .4316 | .2869 | .1196 | .0863 | .0319 | .0283 | .0082 | .0041 | .0017 | .0014 |

A '+' designates a value greater than 0.0 but less than 0.0001.

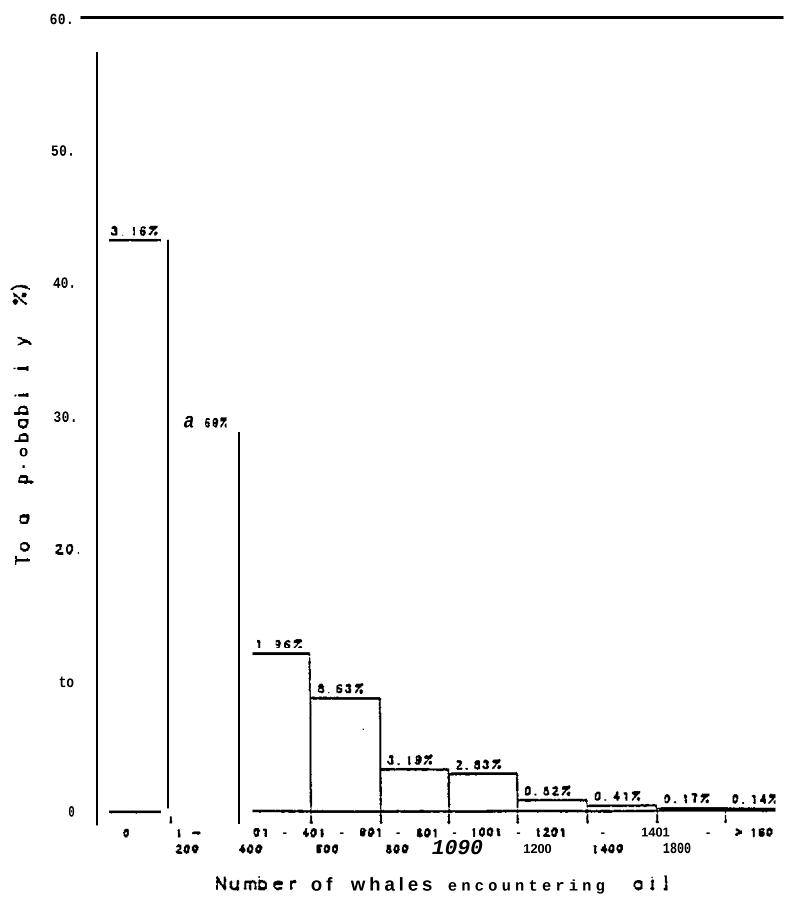



Figure 9-1. Total probability distribution of the number of bowhead whales encountering spilled oil in the Beaufort Sea planning area. The figure includes the conditional probability of O-8 spills occurring, as shown in the table.

| Number of Spills | Prob. of N Spills | Number of bowhead whale - oil encounters if N spills occur 0 | 1-25,000 | 25,001-50 000 | 50,001-75,000 | 75,001-100,000 | 100,001-125,000 | 125,001-150,000 | 150,001-175,000 | 175,001-200,000 | >200,000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .1959 | .1959 | | | | | | | | | |
| 1 | .3194 | .1551 | .1132 | .0274 | .0110 | .0073 | .0018 | | | .0018 | .0018 |
| 2 | .2603 | .0609 | .1142 | .0432 | .0184 | .0122 | .0039 | .0012 | .0003 | .0023 | .0037 |
| 3 | .1414 | .0160 | .0581 | .0305 | .0147 | .0103 | .0041 | .0019 | .0006 | .0015 | .0036 |
| 4 | .0576 | .0031 | .0198 | ,0142 | .0077 | .0054 | .0026 | .0014 | .0005 | .0007 | .0023 |
| 5 | .0188 | .0005 | .0051 | .0046 | .0030 | .0021 | .0012 | .0007 | .0003 | .0003 | .0010 |
| 6 | .0051 | .0001 | .0010 | .0012 | .0009 | .0006 | .0004 | .0003 | .0001 | .0001 | |
| 7 | .0012 | + | .0002 | .0002 | .0002 | .0002 | .0001 | .0001 | + | + | .0001 |
| 8 | .0002 | + | + | + | + | + | + | + | + | i- | |
| Total Probability | .9999 | .4316 | .3116 | .1213 | .0559 | .0381 | .0141 | .0056 | .0018 | .0067 | .0129 |

A '+' designates a value greater than 0.0 but less than 0.0001.

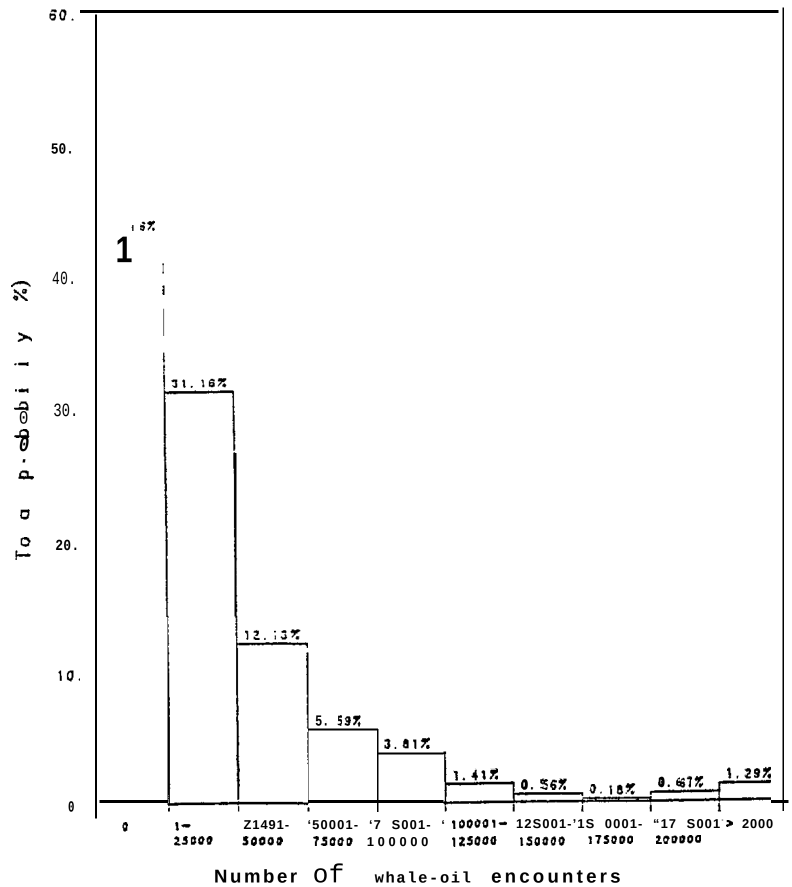



Figure 9-2. Total probability distribution of the number of bowhead whale-oil interactions in the Beaufort Sea planning area. The figure includes the conditional probability of O-8 spills occurring, as shown in the table.

| Number of Spills | Prob. of N Spills | Number of bowhead whale surfacings in oil per 100,000 surfacings 0 | 1-5 | 6-10 | 11-15 | 16-20 | 21-25 | 26-30 | 31-35 | 36-40 | >40 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .1959 | .1959 | | | | | | | | | |
| 1 | .3194 | .1551 | .0511 | .0164 | .0128 | .0201 | .0055 | .0164 | .0110 | .0018 | .0292 |
| 2 | .2603 | .0609 | .0627 | .0365 | .0258 | .0206 | .0088 | .0109 | .0062 | .0043 | .0237 |
| 3 | .1414 | .0160 | .0373 | .0266 | .0177 | .0126 | .0075 | .0069 | .0045 | .0023 | .0099 |
| 4 | .0576 | .0031 | .0161 | .0125 | .0080. | .0050 | .0046 | .0022 | .0016 | .0010 | .0036 |
| 5 | .0188 | .0005 | .0047 | .0065 | .0030 | .0022 | .0012 | .0009 | .0004 | .0002 | .0012 |
| 6 | .0051 | ,0001 | .0012 | .0013 | .0009 | .0006 | .0004 | .0002 | .0001 | .0001 | .0003 |
| 7 | .0012 | + | .0003 | .0003 | .0002 | .0001 | .0001 | + | + | + | .0001 |
| 8 | .0002 | + | + | .0001 | .0001 | + | + | + | + | + | + |
| Total Probability | .9999 | .4316 | .1734 | .0982 | .0685 | .0612 | .0281 | .0375 | .0238 | .0097 | .0680 |

* A '+' designates a value greater than 0.0, but less then 0.0001.

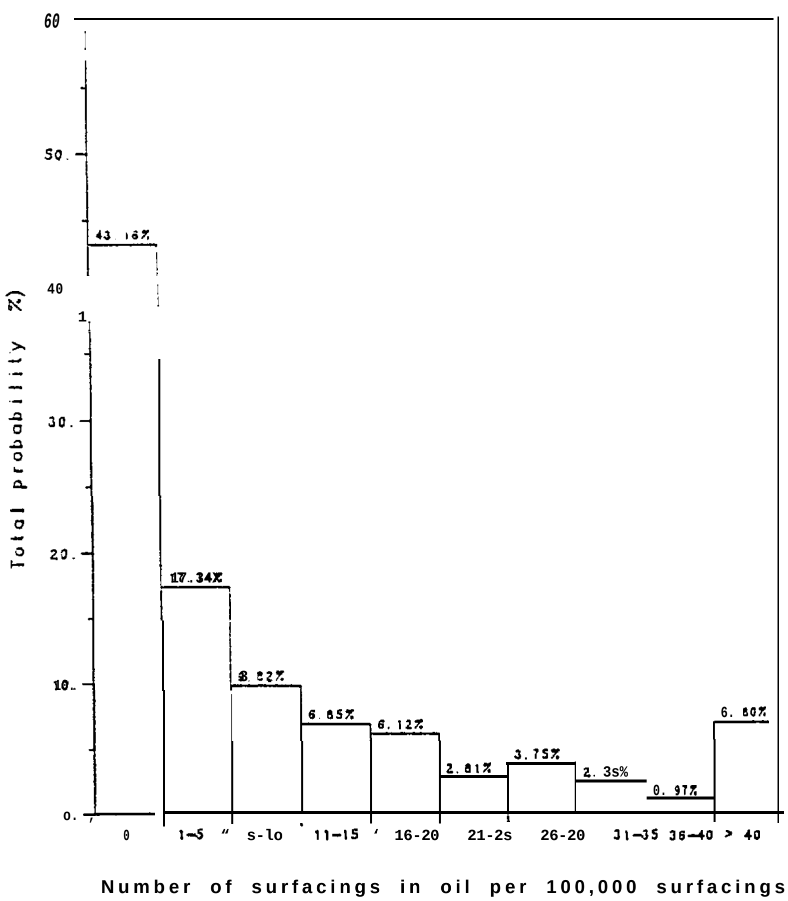



Figure 9-3. Total probability distribution of the number of bowhead whale surfacings in oil per 100,000 surfacings while spills are present in the Beaufort Sea. The figure includes the conditional probability of O-8 spills occurring, as shown in the table.

Number of gray whales oiled if N spills occur

| Number of Spills | Prob. of N Spills | o _ | 1-100 | 101-200 | 201-300 | 301-400 | 401-500 | 501-600 | 601-700 | 701-800 | >800 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .1959 | .1959 | | | | | | | | | |
| 1 | .3194 | .3066 | .0055 | .0055 | | | .0018 | | | | |
| 2 | .2603 | .2399 | .0085 | .0087 | .0001 | .0001 | .0030 | .0001 | | | |
| 3 | .1414 | .1252 | .0067 | .0069 | .0002 | + | .0023 | + | | | + |
| 4 | .0576 | .0490 | .0034 | .0037 | .0001 | + | .0012 | .0001 | | | + |
| 5 | .0188 | .0153 | .0013 | .0015 | .0001 | + | .0005 | + | | | + |
| 6 | .0051 | .0040 | .0004 | .0005 | + | + | .0002 | + | + | | + |
| 7 | .0012 | .0009 | .0001 | .0001 | + | + | + | + | + | | + |
| 8 | .0002 | .0002 | + | + | + | + | + | + | + | | + |
| Total Probability | .9999 | .9370 | .0259 | .0269 | .0005 | .0001 | .0090 | .0002 | + | | + |

A ‘i-’ designates a value greater than 0.0 but less than 0.0001.

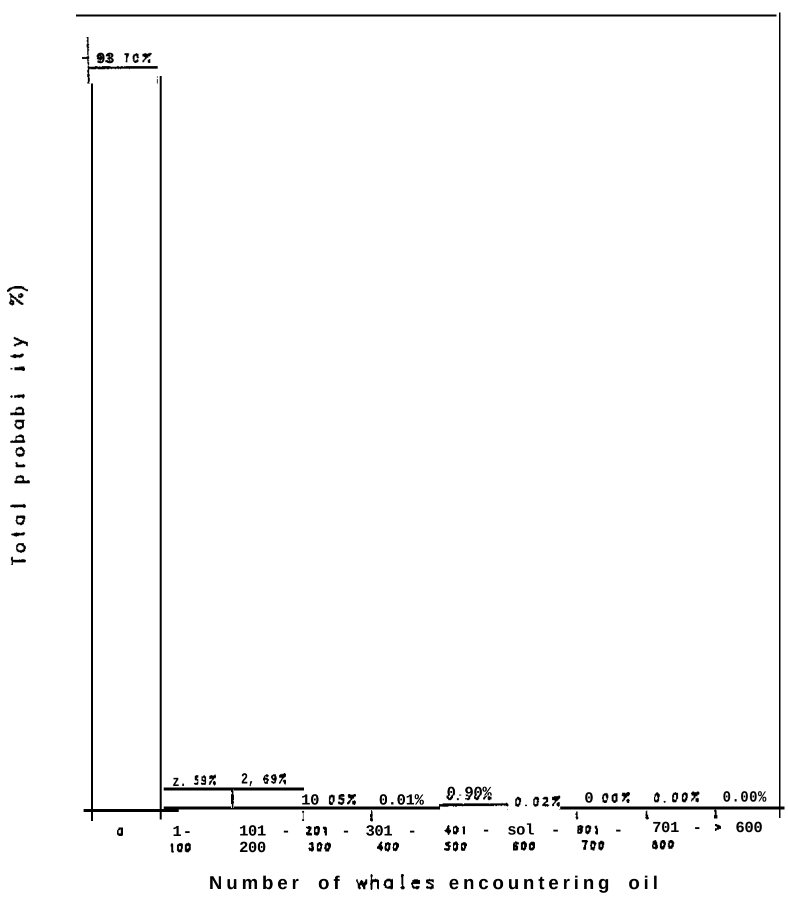



Figure 9-4. Total probability distribution of the number of gray whales encountering spilled oil in the Beaufort Sea planning area. The figure includes the conditional probability of O-8 spills occurring, as shown in the table.

| Number of Spills | Prob. of N Spills | 0 | 1-5 | 6-10 | 11-15 | 16-20 | 21-25 | 26-30 | 31-35 | 36-40 | >40 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Number of gray whale surfacings in oil per 100,000 surfacings | | | | | | | | | |
| 0 | .1959 | .1959 | | | | | | | | | |
| 1 | .3194 | .3066 | .0091 | .0018 | | | .0018 | | | | |
| 2 | .2603 | .2399 | .0173 | + | .0031 | | | | | | |
| 3 | .1414 | .1252 | .0138 | .0024 | + | | | | | | |
| 4 | .0576 . | .0490 | .0073 | .0013 | + | | | | | | |
| 5 | .0188 | .0153 | . 0034 | + | | | | | | | |
| 6 | .0051 | .0040 | .0011 | + | | | | | | | |
| 7 | .0012 | .0009 | .0003 | i· | | | | | | | |
| 8 | .0002 | ,0002 | .0001 | + | | | | | | | |
| To tal Probability | .9999 | .9370 | .0524 | .0055 | .0031 | | .0018 | | | | |

* A '+' designates a value greater than 0.0 but less than 0.0001.

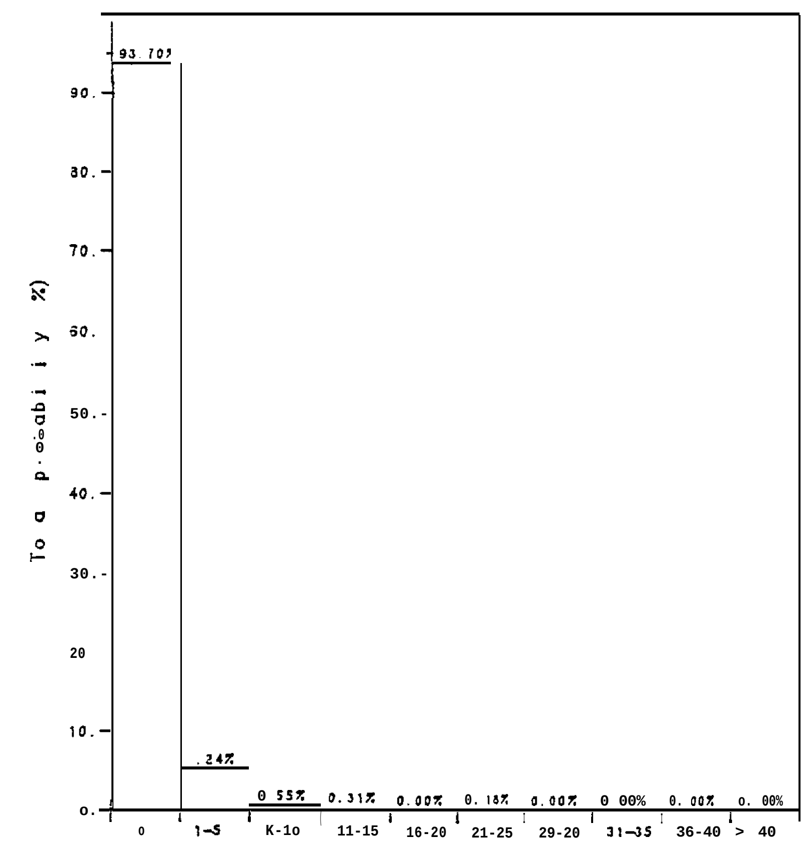



Figure 9-6. Total probability distribution of the number of gray whale surfacings in oil per 100,000 surfacings while spills are present in the Beaufort Sea. The figure includes the conditional probability of O-8 spills occurring, as shown in the table.

## 10. summary

The model system described in this report was developed to quantitatively assess the probability that endangered bowhead and gray whales will encounter spilled oil in Alaskan waters. An oil spill trajectory model, bowhead and gray whale migration models and a diving-surfacing model comprise the model system. The migration and diving-surfacing models were developed from theoretical considerations, then calibrated with observations of whale distributions. The oil spill model, developed under a series of other contracts, accounts for transport and spreading behavior in open water and in the presence of sea ice. Historical wind records and heavy, normal, or light ice cover data sets are selected at random to provide stochastic oil spill scenarios for whale-oil interaction simulations.

Sensitivity studies have been performed to assess the extent to which model output variability is related to specific model system parameters or components. The results of these studies can be summarized as follows:

(1) as the number of discrete points used to represent the population increases, the mean total exposure time (i.e., total time whale points are within the bounds of an oil slick) stabilizes;

(2) the variability of the exposure time estimate due to the stochastic components of the migration model exceeds that due to number of discrete points at about 500 points;

(3) a timestep exceeding the 3 hour timestep used to run the oil spill model results in erroneous estimates of whale-oil interactions;

(4) the dive time model contributes only a small fraction of the total variability of the interaction estimates;

(5) 25 randomly selected scenarios are sufficient to avoid bias in the results due to inter-annual variability;

(6) inter-annual variability in weather scenarios, and therefore the difference between one oil spill trajectory and another, represents the major source of variability in whale-oil spill interaction estimates.

The models were applied to 5 launch points within each of 4 Alaskan OCS planning areas: Navarin Basin, Beaufort Sea, Chukchi Sea and St. George Basin. In the Navarin Basin planning area, simulations showed only bowhead whales encountered oil. A spill occurring between the months of November and April in the southern portion of the planning area, where approximately one-third of the bowhead population was assumed to spend the winter, posed the only potential for impacting bowhead whales.

The spill scenarios at all 5 launch points investigated in the Beaufort Sea resulted in the oiling of an average of 1-5% of the bowhead population. Spills at the Beaufort sites located near Pt. Barrow could impact a small percentage (less than 0.2%) of gray whales utilizing the Alaskan Chukchi Sea for feeding in the summer. Total probabilities for whale - oil spill encounters were computed for the Beaufort Sea planning area; for reasons discussed in detail in Section 9, these results are quantitatively unreliable, but serve to exemplify the methodology. Total probabilities for bowhead and gray whales encountering oil spilled in the Beaufort Sea were calculated to be approximately 57% and 6%, respectively, assuming the mean number of spills occurring *is* 1.63. The high probability of bowhead whales encountering oil, despite a low number of expected spills, results from spills at all sites contacting whales. The overall impact of "spilled oil can be put in perspective by examining the relative number of surfacings occurring in oil over the spill duration. For bowhead whales there is greater than an 83% probability that 20 or fewer of every 100,000 surfacings will be in oil. For gray whales there is approximately a 99% probability that 5 or fewer of every 100,000 surfacings will be in oil, while spilled oil is present.

Spills in the Chukchi Sea have the potential of impacting both bowhead and gray whales. Oil which is released in the spring and becomes trapped by ice may impact both species if it persists in the area until gray whales arrive. During simulated oil spill scenarios from the 5 Chukchi sites, 0-1.5% of the bowhead whales and 0-1.4% of the gray whales encountered oil.

Spills in the St. George Basin planning *area* will probably have no impact on bowhead whales. Only simulated spills occurring in Unimak Pass resulted in gray whales encountering oil, with an average of about 3% of the population surfacing in oil.

The model system simulations performed for the 4 Alaskan OCS planning areas discussed herein indicate that oil spills are unlikely to affect a significant portion of either endangered whale population. In all cases the number of whale surfacings in oil is small relative to the total number of surfacings occurring over the duration of a spill. Simulations did indicate that oil spilled at certain sites and seasons had a higher probability of contacting whales. Restricting oil related activities near these sites during the season(s) of greatest danger could significantly reduce the probability of whales encountering oil. In the Navarin Basin, this would involve activities at sites near St. Matthew Island in the winter and spring to reduce the possibility of bowhead whales contacting spilled oil. In the St. George Basin, activities at sites in and near Unimak Pass pose a possibility of gray whales encountering oil should a spill occur during April-May or November-December.

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# Appendices

Summary Tables of Whale-Oil Interactions
for Each Planting Area

Table of Contents

Overview of Appendix

The appendix contains the raw data used to generate the probability of encounter histograms for each whale species in each planning area. Each table contains the output of the diving-surfacing model, which converts time-in-oil to a number of surfacings (hits) in oil. To reduce the bulk of the appendix, only the values calculated at 10 days after the last oil release are presented.

The appendix is organized such that the results for each planning area are presented in a separate section (Sections A-D). Within each section the simulation results are grouped by spill site and season into tables. Each table gives the number of whale points encountering oil and the number of surfacings in oil for each spill scenario that resulted in whales encountering oil. If a scenario did not result in any whale-oil encounters, it was omitted from the table. If none of the 25 scenarios for a particular site and season resulted in whale-oil encounters, no table is included for that site and season.

Table A. 1 Number of surfacings in oil and time in oiled water for individual whale points for each spill scenario at Navarin site 1 (10,000 bbl spills) resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 7. 6 bowhead whales.

RUN 2: 494 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 56 | 152 | 2.4 |
| 61 | 72 | 0.6 |
| 79 | 1 60 | 2.2 |
| 387 | 124 | 2.4 |
| 390 | 30 1 | 3. 1 |
| 409 | 73 | 2.0 |
| Totals: 6 | 882 | 12.7 |

RUN 3: 493 paints from a total of 500 points did nut hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 174 | 400 | 5. 2 |
| 229 | 417 | 5. 0 |
| 269 | 48 | 1. 3 |
| 312 | 74 | 1. 6 |
| 313 | 353 | 3. 0 |
| 434 | 150 | 3. 0 |
| 442 | 245 | 3. 5 |
| Totals: 7 | 1687 | 22.6 |

RUN 4: 486 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in Oil (hrs) |
|---|---|---|
| 5 | 130 | 1.2 |
| 143 | 335 | 5.9 |
| 208 | 165 | 3.1 |
| 255 | 657 | 7.8 |
| 261 | 456 | 6.9 |
| 292 | 457 | 8.0 |
| 307 | 14'7 | 0.9 |
| 317 | 649 | ?.3 |
| 332 | 111 | 1.5 |
| 341 | 1181 | 12.9 |
| 370 | 1124 | 18.4 |
| 416 | 775 | 13.3 |
| 458 | 82 | 1.2 |
| 480 | 77 | 0.9 |
| Totals: 14 | 6550 | ?1.3 |

RUN 5: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 175 | 321 | 4.4 |
| 317 | 29 1 | 5.0 |
| Totals: 2 | 612 | 7.4 |

RUN 6: 482 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in Oil (hrs) |
|---|---|---|
| 11 | 178 | 2.6 |
| 29 | 77 | 1.0 |
| 47 | 9 | 0.4 |
| 61 | 18 | 0.1 |
| 83 | 1 | 0.0 |
| 127 | 31 | 0.3 |
| 152 | 37 | 1.2 |
| 175 | 76 | 0.7 |
| 180 | 115 | 1.7 |
| 324 | 92 | 1.3 |
| 328 | 59 | 0.9 |
| 334 | 8 | Q.3 |
| 393 | 7? | 1.0 |
| 424 | 82 | 1.0 |
| 446 | 144 | 1.3 |
| 468 | 19 | 0.6 |
| 48'7 | 20 | 0.1 |
| 491 | 91 | 0.8 |
| Totals: 18 | 1138 | 15.3 |

RUN 7: 487 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 17 | 62 | 0.9 |
| 140 | 79 | 1.() |
| 1 80 | 572 | 0.6 |
| 225 | 1654 | 22.8 |
| 235 | 1 034 | 16.2 |
| 240 | 497 | 6.2 |
| 391 | 118 | 1.5 |
| 408 | 83 | 1.2 |
| 417 | 1 52 | 1.3 |
| 446 | 18 | 0.1 |
| 456 | 191 | 3.6 |
| 465 | 26 | 0.6 |
| 495 | ?1 | 1.5 |
| Totals: 13 | 4377 | 64.5 |

RUN 9: 495 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 20 | 124 | 2.8 |
| 194 | 155 | 1.8 |
| 232 | 164 | 2.7 |
| 327 | 65 | 1.0 |
| 417 | 136 | 1.6 |
| Totals: 5 | 1544 | 9.9 |

RUN 10: 490 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 5 | 70 | 0.8 |
| 36 | 243 | 3.9 |
| 127 | 36 | 0.5 |
| 241 | 77 | 1.4 |
| 255 | 128 | 2.3 |
| 257 | 10 | 0.4 |
| 342 | 63 | 0.5 |
| 353 | 135 | 1.9 |
| 40? | 30 | C). 5 |
| 4215 | 252 | 3. 8 |
| Totals: 10 | 1052 | 16.0 |

RUN 11: 494 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 25 | 101 | 1.3 |
| 129 | 284 | 4.5 |
| 150 | 337 | 4.4 |
| 228 | 3% | 0.7 |
| 309 | 256 | 3.9 |
| 400 | 46 | 1.0 |
| Totals: 6 | 1062 | 15.8 |

RUN 12: 499 points from a total of 500 points did not hit oil.

| Whale pt II? # | # of hits | Time in oil (hrs) |
|---|---|---|
| 36 | 169 | 2.6 |
| Totals: 1 | 169 | 2.6 |

RUN 13: 486 points from a total of 5(X) points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 29 | 419 | 6.7 |
| 47 | 50 | 0.9 |
| 83 | 707 | 9.3 |
| 118 | 83 | 0.9 |
| 163 | 37 | 0.6 |
| 185 | 67 | 0.7 |
| 188 | 426 | 6.4 |
| 240 | 53 | 1.0 |
| 29 1 | 528 | 6.8 |
| 333 | 82 | 1.0 |
| 337 | 105 | 1.5 |
| 361 | 34 | 0.4 |
| 409 | 9s | 0.8 |
| 4151 | 8a | 1.1 |
| Totals: 14 | 2777 | 38.1 |

RUN 15: 495 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 53 | 40 | 1.0 |
| 136 | 335 | 3.7 |
| 239 | 502 | 5. El |
| 241 | 99 | 2.7 |
| 446 | 51 | 1. 1 |
| Totals: 5 | 1027 | 14.3 |

RUN 16: 493 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 23 | 318 | 6. 0 |
| 29 | 77 | 1.6 |
| 177 | 106 | #. 7 |
| 230 | 246 | 4.2 |
| 255 | 512 | 6. 5 |
| 293 | 32 | 1. 1 |
| 416 | 112 | 2. 2 |
| Totals: 7 | 1403 | 22. 3 |

RUN 17: 485 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 20 | 161 | 1. 7 |
| 78 | 57 | 0.6 |
| 88 | 38 | 1. 3 |
| 151 | 174 | 1. 9 |
| 194 | 36 | 0.5 |
| 240 | 128 | 1. 1 |
| 241 | 78 | 0. 8 |
| 257 | 146 | 0.9 |
| 332 | 86 | 2.3 |
| 340 | 68 | 1.7 |
| 343 | 174 | 1. 9 |
| 39 i | 116 | 1. 1 |
| 399 | 111 | 1. 9 |
| 418 | 26 | 0. 5 |
| 463 | 2 | 0.4 |
| Totals: 15 | 1403 | 18.6 |

RUN 23: 491 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 25 | 3s | 1.5 |
| 53 | 136 | 1.3 |
| 158 | 113 | 1.3 |
| 1 80 | 51 | 0.5 |
| 101 | 111 | 1.3 |
| 15$4 | 212 | 3.9 |
| 225 | 29 | 0. 6 |
| 246 | 92 | 0. 8 |
| 348 | 115 | 1.7 |
| Totals: 9 | 8?4 | 12. 9 |

RUN 24: 497 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 122 | 334 | 5. 6 |
| 1 62 | 670 | 10. 9 |
| 313 | 239 | 5.5 |
| Totals: 3 | 1243 | 22. 0 |

Table A.2 Number of surfacings in oil and time in oiled water for individual whale paints for each spill scenario at Navarin site 4 resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 7. & bowhead whales.

RUN 18: 495 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 98 | 39 | 1.0 |
| | 117 | 419 | 5.3 |
| | 1 ?2 | 81 | 1. 1 |
| | 426 | 352 | 4'. 1 |
| | 498 | 88 | 0. 7 |
| Totals: | 5 | 979 | 12.2 |

Table B. 1 Number of surfacings in oil and time in oiled water for individual bowhead whale points for each spill scenario at Beaufort site 1 resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale paints: each whale point represents 7. & bowhead whales.

RUN 2: 498 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 11 | 202 | 2.7 |
| | 313 | 269 | 3.4 |
| Totals: | 2 | 471 | 6.2 |

RUN 4: 478 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in ail (hrs) |
|---|---|---|---|
| | 70 | 250 | 4. 0 |
| | 87 | 286 | 4. 1 |
| | 96 | 379 | 5. 8 |
| | 109 | 129 | 2. 2 |
| | 111 | 88 | 0. 7 |
| | 116 | 157 | 1.7 |
| | 184 | 397 | 5.9 |
| | 187 | 79 | 1.4 |
| | 3.90 | 91 | 0. 9 |
| | 210 | 40 | 1.3 |
| | 217 | 133 | 1. & |
| | 241 | 71 | 0.6 |
| | 266 | 90 | 1. 4 |
| | 267 | 139 | 1. 5 |
| | 328 | 186 | 2.7 |
| | 364 | 355 | 5. 1 |
| | 376 | 264 | 2.7 |
| | 415 | 7 | 5.0 |
| | 450 | 114 | 1. 9 |
| | 459 | 251 | 3. 6 |
| | 469 | 382 | 4.6 |
| | 474 | 244 | 3.8 |
| Totals: | 22 | 4132 | 57.5 |

RUN S: 482 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 60 | 1005 | 13.4 |
| 200 | 249 | 3.6 |
| 219 | 353 | 3.6 |
| 224 | 239 | 3.7 |
| 227 | 1112 | 15.7 |
| 259 | 15 | 0.2 |
| 276 | 296 | 3.7 |
| 279 | 131 | 2.2 |
| 295 | 150 | 2.7 |
| 320 | 118 | 3.6 |
| 385 | 312 | 4.3 |
| 410 | 199 | 3. 5 |
| 420 | 2262 | 34.9 |
| 428 | 314 | 3.4 |
| 431 | 7 | 0. 0 |
| 435 | 12!5 | 3.6 |
| 460 | 142S | 15. 3 |
| 461 | 157 | 1. 6 |
| ------- | --------- | ----------------- |
| Totals: 18 | 8473 | 119. 0 |

RUN 6: 442 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 9 | 643 | 9.9 |
| 28 | 1104 | 17.2 |
| 44 | 338 | 5.3 |
| 46 | 235 | 3.3 |
| 73 | 318 | 4.3 |
| 77 | 3115 | 40.6 |
| 85 | 325 | 4.8 |
| 88 | 648 | 9.5 |
| 93 | 204 | 3.2 |
| 110 | 191 | 2.8 |
| 116 | 34 | 0.4 |
| 130 | 303 | 5.0 |
| 152 | 1535 | 22.1 |
| 188 | 21 | 0.5 |
| 191 | 665 | 10.3 |
| 203 | 188 | 2.3 |
| 204 | 1?7 | 2.6 |
| 211 | 469 | 5.9 |
| 225 | 261 | 2.2 |
| 226 | 2722 | 39.1 |
| 232 | 1336 | 19.2 |
| 235 | 750 | 10.2 |
| 257 | 246 | 3.1 |
| 265 | 1410 | 24.9 |
| 267 | 2813 | 40.6 |
| 270 | 472 | 5.1 |
| 273 | 772 | 8.8 |
| 276 | 1700 | 24.1 |
| 278 | 1030 | 16.3 |
| 2B4 | 2558 | 37.0 |
| 292 | 692 | 7.4 |
| 2?9 | 750 | 10.3 |
| 309 | 312 | 5.3 |
| 320 | 850 | 12.3 |
| 321 | 2959 | 41.1 |
| 347 | 3651 | 57.0 |
| 350 | 96 | 1.6 |
| 351 | 5 | 1.1 |
| 356 | 2890 | 33.7 |
| 357 | 1155 | 18.1 |
| 359 | 768 | 11.6 |
| 372 | 1054 | 15.4 |
| 377 | 1157 | 15.7 |
| 3s7 | 425 | 5.8 |
| 3?0 | 247 | 2.3 |
| 393 | 715 | 9.1 |
| 402 | 1515 | 22.9 |
| 410 | 800 | 11.8 |
| 416 | 586 | 6.B |
| 421 | 920 | 13.1 |
| 434 | 17 | 0.2 |
| 464 | 1577 | 26.1 |
| 468 | 1172 | 18.5 |
| 469 | 636 | 9.2 |
| 471 | 29 | 0.4 |
| 472 | 237 | 4.0 |
| 492 | 201 | 2.9 |
| 4'75 | 2043 | 24.9 |
| **Totals:** 58 | 54052 | 770.7 |

RUN 7: 482 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| i | 88 | 0.4 |
| 1? | 133 | 1.5 |
| 65 | 100 | 1.0 |
| 82 | 147 | 1.5 |
| 85 | 97 | 2. 1 |
| 147 | 175 | 2.6 |
| 198 | 5 | 0. El |
| 220 | 141 | 0.9 |
| 304 | 67 | 0.8 |
| 306 | 136 | 1. 1 |
| 337 | 146 | 2.2 |
| 342 | 113 | 1.6 |
| 349 | 305 | 3.4 |
| 362 | 48 | 1.9 |
| 301 | 107 | 1.0 |
| 409 | 37 | 0.8 |
| 421 | 136 | 1.9 |
| 432 | 80 | 1.0 |
| Totals: la | 2021 | 26.7 |

RUN 11: 469 points from a total of '500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 27 | 81 | 1. 1 |
| 32 | 148 | 2.4 |
| 66 | 73 | 0. 9 |
| 70 | 6? | 1.4 |
| 75 | 121 | 1. 8 |
| 95 | 62 | 0.6 |
| 107 | 103 | 1.4 |
| 116 | 60 | 1. 1 |
| 118 | 103 | 1,3 |
| 123 | 161 | 2. 8 |
| 151 | 142 | 1..6 |
| 170 | 71 | 1.3 |
| 182 | 120 | 1. B |
| 187 | 44 | 0.4 |
| 215 | 20 | 0. 1 |
| 241 | 121 | 1.6 |
| 252 | 297 | 2.7 |
| 269 | 10 | 0. 1 |
| 2a2 | 180 | 2. 1 |
| 297 | 224 | 2.9 |
| 299 | 202 | 2.7 |
| 308 | 211 | 1.7 |
| 319 | 147 | 2.6 |
| 330 | 122 | 1.6 |
| 359 | 48 | 0.9 |
| 379 | 286 | 4.2 |
| 392 | 94 | 0.8 |
| 412 | 85 | 1. 1 |
| 461 | 35 | 0.4 |
| 466 | 29 | 1.0 |
| 473 | 105 | 0. 9 |
| Totals: 31 | 3494 | 47.0 |

RUN 13: 391 pointsfrom a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs ) |
|---|---|---|
| 1 | 171 | 1.8 |
| 2 | 44 | 1.1 |
| 4 | 23 | 0.5 |
| 6 | 91 | 1.4 |
| 9 | 280 | 2.4 |
| 12 | 50 | 0.4 |
| 27 | 58 | 0.9 |
| 39 | 131 | 1.2 |
| 41 | 17 | 0.5 |
| 40 | 1 | 0.4 |
| 49 | 32 | 0.9 |
| 53 | 10 | 0.1 |
| 55 | 39 | 0.9 |
| 59 | 141 | 2.8 |
| 62 | 288 | 2.4 |
| 65 | 58 | 0.6 |
| 69 | 71 | 1.4 |
| 79 | 39 | 0.5 |
| 80 | 60 | 0.5 |
| 82 | 122 | 1.9 |
| 84 | 91 | 0.b |
| 85 | 341 | 4.9 |
| 104 | 36 | 0.s |
| 106 | 371 | 5.2 |
| 124 | 97 | 1.6 |
| 135 | 30 | 0.7 |
| 136 | 9 | 0.2 |
| 137 | 85 | 0.7 |
| 143 | 134 | 1.6 |
| 144 | 4 | 0 5 |
| 145 | 5 | 0.5 |
| 146 | 60 | 0.9 |
| 155 | 11 | 0.6 |
| 160 | 15 | 0.8 |
| 165 | 50 | 0.9 |
| 167 | 16 | 0 4 |
| 1 69 | 109 | 0.6 |
| 170 | 146 | 2.3 |
| 178 | 103 | 1.1 |
| 180 | 54 | 0.8 |
| 182 | 13 | 0 4 |
| 183 | b | 0 1 |
| 194 | 100 | 0.9 |
| 197 | 422 | 6.7 |
| 19? | 67 | 1.0 |
| 201 | 29 | 0 9 |
| 204 | 82 | 1.1 |
| 205 | 204 | 2.6 |
| 206 | 3 | 0.3 |
| 207 | 69 | 0.6 |
| 20s | 49 | 0.3 |
| 213 | 1 60 | 2.5 |
| 219 | 40 | 0.9 |
| 222 | 58 | 0.6 |
| 225 | 156 | 2 1 |
| 232 | 30 | 1.1 |
| 239 | 9 | 0.0 |
| 256 | 91 | 0.8 |
| 257 | 97 | 1.9 |
| 259 | t 13 | 1 3 |
| 266 | 249 | 3 s |
| 267 | 110 | 1.5 |
| 269 | 147 | 1 3 |
| 272 | 27 | t. 1 |
| 280 | 161 | 1.0 |
| 28 1 | 26 | 0.8 |
| 289 | 439 | 4.7 |
| 290 | 246 | 3.1 |
| 297 | 80 | 1.4 |
| 300 | 64 | 0.3 |
| 30B | 330 | 4.3 |
| 315 | 33 | 0.4 |
| 316 | 39 | 0.6 |
| 323 | 111 | 1.3 |
| 324 | 211 | 4.3 |
| 330 | 22 | 0.3 |
| 333 | 114 | 0.9 |
| 33.4 | 27 | 0.4 |
| 345 | 60 | 0.7 |
| 346 | 45 | 0.3 |
| 347 | 269 | 4.3 |
| 353 | 76 | 1.1 |
| 358 | 69 | 0.8 |
| 367 | 72 | 0.8 |
| 370 | 186 | 1.9 |
| 376 | 301 | 3.7 |
| 379 | 19 | 0.i |
| 385 | 261 | 2.9 |
| 405 | 18 | 0.9 |
| 406 | 233 | 4.6 |
| 409 | 290 | 3.9 |
| 412 | 7s | 1.2 |
| 420 | 154 | 2.1 |
| 425 | 130 | 1.2 |
| 434 | 15 | 0.3 |
| .439 | 67 | 0.8 |
| 448 | 86 | 0.9 |
| 449 | 31 | 0.? |
| 4S2 | 40 | 0.7 |
| 458 | 27 | 0.4 |
| 460 | 44 | 1.2 |
| 461 | 269 | 3.? |
| 462 | 40 | 0.3 |
| 466 | 144 | 1.? |
| 471 | 115 | 1 2 |
| 474 | 122 | 1.8 |
| 4e4 | 217 | 2.8 |
| 490 | 205 | 1 ? |
| 493 | ?29 | 2.b |
| Totals: 109 | 11647 | 158.8 |

RUN 15: 421 points from a total of 500 points did not hit oil

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 2 | 92 | 1.7 |
| 3 | 8 | 0.4 |
| 9 | 102 | 0.9 |
| 18 | 4 | 0.2 |
| 34 | 39 | 0.9 |
| 37 | 106 | 1.5 |
| 40 | 201 | 2.7 |
| 48 | 61 | 0.6 |
| 49 | 86 | 0.6 |
| 51 | 26 | 0.2 |
| 55 | 78 | 0.8 |
| 57 | 108 | 1.3 |
| 58 | 129 | 1.3 |
| 93 | 147 | 2.8 |
| 101 | 20 | 0.7 |
| 102 | 43 | 0.5 |
| 106 | 43 | 0.4 |
| 108 | 103 | 0.7 |
| 119 | 144 | 1.4 |
| 117 | 63 | 0.5 |
| 122 | 102 | 1.1 |
| 135 | 62 | 2.3 |
| 148 | 91 | 1.3 |
| 155 | 133 | 0.7 |
| 168 | 19 | 0.3 |
| 170 | 73 | 0.5 |
| 171 | 312 | 3.9 |
| 173 | 59 | 2.0 |
| 177 | 57 | 0.9 |
| 180 | 68 | 0.9 |
| 185 | 46 | 2.3 |
| 170 | 165 | 1.1 |
| 194 | 26 | 0.2 |
| 1?7 | 25 | 0.5 |
| 198 | 92 | 0.7 |
| 209 | 33 | 0.5 |
| 208 | 63 | 1.1 |
| 211 | 106 | 1.5 |
| 217 | 126 | 1.8 |
| 236 | 114 | 1.2 |
| 240 | 80 | 0.8 |
| 241 | 233 | 3.9 |
| 244 | 94 | 0.8 |
| 246 | 81 | 1.5 |
| 254 | 130 | 1.3 |
| 256 | 146 | 2.3 |
| 285 | 332 | 6.4 |
| 289 | 61 | 1.1 |
| 291 | 78 | 2.5 |
| 313 | 38 | 0.3 |
| 317 | 151 | 2.2 |
| 321 | %02 | 2.5 |
| 323 | 78 | 1.5 |
| 332 | 27 | 0.4 |
| 333 | 44 | 0.2 |
| 336 | 42 | 0.7 |
| 342 | 49 | 0.7 |
| 352 | 67 | 1.2 |
| 360 | 125 | 1.9 |
| 364 | 26 | 1.0 |
| 365 | 192 | 2.4 |
| 366 | 26 | 0.4 |
| 367 | 125 | 2.0 |
| 371 | 68 | 1.3 |
| 373 | 93 | 0.7 |
| 375 | 22 | 0.6 |
| 391 | 140 | 1.3 |
| 399 | 78 | 1.2 |
| 400 | 99 | 1.8 |
| 410 | 54 | 0.9 |
| 428 | 37 | 0.7 |
| 437 | 11 | 0.3 |
| 430 | 164 | 2.5 |
| 45a | 128 | 1.1 |
| 465 | 13 | 0.9 |
| 470 | 31 | 0.8 |
| 472 | 40 | 0.9 |
| 484 | 85 | 1.1 |
| 494 | 76 | 1.3 |
| Totals: 79 | 6927 | 99.5 |

RUN 17: 483 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 10 | 75 | 0.8 |
| 24 | 10s | 1.2 |
| 61 | 152 | 2.9 |
| 116 | 119 | 1.9 |
| 132 | 228 | 1.9 |
| 191 | 154 | 1.6 |
| 233 | 67 | 1.8 |
| 246 | 251 | 3.6 |
| 282 | 41 | 0.4 |
| 324 | 134 | 1.5 |
| 335 | 11 | 0.2 |
| 355 | 199 | 2.0 |
| 392 | 112 | 2.3 |
| 396 | 107 | 2.1 |
| 430 | 4 | 0.7 |
| 483 | 107 | 0.8 |
| 498 | 191 | 1.7 |
| Totals: 17 | 2062 | 28.3 |

RUN 18: 492 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 53 | 50 | 1.0 |
| 234 | 101 | 1.1 |
| 262 | 106 | 1.8 |
| 332 | 31 | 1.1 |
| 392 | 1 | 0.0 |
| 413 | 44 | 0.7 |
| 435 | 137 | 2.9 |
| 449 | 41 | 0.8 |
| Totals: 8 | 511 | 9.3 |

RUN 19: 446 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 6 | 41 | 1.0 |
| 19 | 152 | 0.9 |
| 22 | 57 | 0.8 |
| 23 | 19 | 0.9 |
| 28 | 20 | 0.4 |
| 35 | 68 | 0.5 |
| 38 | 3 | 0.2 |
| 42 | 85 | 0.9 |
| 48 | 115 | 0.9 |
| 53 | 56 | 0.7 |
| 55 | 142 | 1.6 |
| 61 | 44 | 1.1 |
| 96 | 49 | 0.5 |
| 102 | 50 | 0.8 |
| 104 | 32 | 0.9 |
| 113 | 153 | 1.0 |
| 119 | al | 0.8 |
| 134 | 67 | 0.4 |
| 137 | 140 | 1.0 |
| 164 | 53 | 0.8 |
| 191 | 238 | 2.4 |
| 198 | 12 | 0.1 |
| 209 | 99 | 1.4 |
| 212 | 46 | 0.7 |
| 220 | 54 | 0.5 |
| 229 | 70 | 1.0 |
| 236 | 72 | 0.8 |
| 239 | 96 | 1.3 |
| 250 | 61 | 1.1 |
| 253 | 48 | 0.8 |
| 271 | 9 | 0.1 |
| 276 | 49 | 0.6 |
| 280 | 12 | 0.4 |
| 286 | 88 | 1.1 |
| 28? | 30 | 0.El |
| 298 | 61 | 0.9 |
| 357 | 200 | .2.8 |
| 358 | 415 | 1.0 |
| 363 | 73 | 1.2 |
| 372 | 64 | 0.? |
| 375 | 130 | 2.1 |
| 3a3 | 51 | 0.8 |
| 405 | 82 | 0.7 |
| 406 | 107 | 1.0 |
| 408 | 83 | 0.9 |
| 433 | 61 | 0.9 |
| 442 | 72 | 0.4 |
| 447 | 91 | 1.2 |
| 449 | 37 | 0.4 |
| 459 | 63 | 0.8 |
| 469 | 3s | (?.6 |
| 48? | 24 | 0.2 |
| 497 | 58 | 1.1 |
| 498 | 109 | 1.3 |
| Totals: 54 | 3897 | 4a.8 |

RUN 20: 477 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 4 | 192 | 2.3 |
| | 10 | 39 | 0.6 |
| | 74 | 109 | 1.3 |
| | 126 | 109 | 1.8 |
| | 129 | 44 | 0.6 |
| | 135 | 96 | 1.3 |
| | 145 | 99 | 1.5 |
| | 164 | 99 | 1.8 |
| | 222 | 101 | 1.9 |
| | 232 | 63 | 1.1 |
| | 255 | 24 | 0.1 |
| | 294 | 144 | 2.1 |
| | 307 | 99 | 1.9 |
| | 312 | 76 | 1.4 |
| | 317 | 282 | 4.3 |
| | 351 | 7 | 0.2 |
| | 363 | 149 | 1.3 |
| | 390 | 89 | 1.3 |
| | 398 | 44 | 0.3 |
| | 399 | 212 | 2.1 |
| | 457 | 20 | 0.5 |
| | 469 | 235 | 3.2 |
| | 496 | 260 | 3.8 |
| Totals: | 23 | 2592 | 36.6 |

RUN 21: 492 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 17 | 110 | 2.2 |
| | 52 | 30 | 0.5 |
| | 75 | 98 | 1.4 |
| | 94 | 47 | 0.4 |
| | 127 | 15 | C).3 |
| | 202 | 96 | 1.2 |
| | 28'5 | 55 | 0.6 |
| | 369 | 48 | 0.6 |
| Totals: | % | 499 | 7.2 |

RUN 22: 428 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 5 | 306 | 4. 5 |
| 6 | 66 | 0. 7 |
| 10 | 110 | 1.4 |
| 21 | 490 | 6.6 |
| 44 | 42 | 1. 1 |
| 61 | 258 | 3.4 |
| 62 | 55 | 1. 1 |
| 67 | 17 | 0.4 |
| 68 | 12 | 0.2 |
| 82 | 87 | 1.2 |
| 99 | 100 | 1.6 |
| 119 | 68 | 1.9 |
| 121 | 401 | 7.3 |
| 122 | 177 | 2.8 |
| 123 | 191 | 2.2 |
| 135 | 109 | 1.6 |
| 147 | 84 | 1.9 |
| 137 | 240 | 3.4 |
| 164 | 143 | 2.3 |
| 166 | 38 | 0.4 |
| 181 | 100 | 1.0 |
| 184 | 304 | 3.7 |
| 188 | 92 | 1.7 |
| 1?2 | 139 | 1.7 |
| 210 | 62 | 1. 5 |
| 213 | 144 | 2.0 |
| 214 | 106 | 1.8 |
| 217 | 127 | 1.5 |
| 226 | 176 | 2.7 |
| 238 | 39 | 0.4 |
| 243 | 41 | 1.2 |
| 243 | 51 | 0. S |
| 249 | 163 | 2.7 |
| 263 | 13s | 1. 5 |
| 264 | 94 | 1.3 |
| 266 | 308 | 2.7 |
| 291 | 6 | 0.0 |
| 299 | 99 | 1.7 |
| 301 | 316 | 4. 1 |
| 315 | 395 | S. 2 |
| 317 | 12 | 0. 1 |
| 318 | 63 | 1. 1 |
| 324 | 96 | 1. 4 |
| 326 | 28 | 0. B |
| 330 | 94 | 2.2 |
| 333 | 139 | 1.7 |
| 336 | 143 | 1.6 |
| 338 | 84 | 1.0 |
| 340 | 136 | 2, 1 |
| 342 | 337 | 5.2 |
| 372 | 164 | 1.6 |
| 384 | 159 | 1. B |
| 395 | 230 | 2.5 |
| 396 | 211 | 3.6 |
| 402 | 138 | 3. 6 |
| 406 | 17 | 0.4 |
| 408 | 1 40 | 1.0 |
| 413 | 163 | 2.7 |
| 419 | 56 | 0. 6 |
| 422 | 394 | 4.3 |
| 423 | 71 | 1, 6 |
| 433 | 14 | 0.2 |
| 434 | 120 | 2.0 |
| 43 5 | 112 | 2.0 |
| 436 | 33 | 0. B |
| 440 | 276 | 3. 3 |
| 460 | 95 | 1.2 |
| 463 | 94 | I. 4 |
| 466 | 200 | 2. a |
| 46? | 56 | 0.5 |
| 491 | 152 | 2.4 |
| 4a4 | 265 | 3.0 |
| Totals: 72 | 10161 | 145. 1 |

Table B.2 Number of surfacings in oil and time in oiled water for individual bowhead whale points for each spill scenario at Beaufort site 2 (spring spills) resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 7.6 bowhead whales.

RUN 3: 499 points From a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 300 | 57 | Q. 6 |
| Totals: 1 | 57 | 0. 5 |

RUN 6: 487 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 205 | 48 | 0.8 |
| 206 | 167 | 2. 8 |
| 213 | 111 | 2. 9 |
| 220 | 4a | u. 7 |
| 265 | 101 | 1. 1 |
| 268 | 79 | 0. 5 |
| 277 | 238 | 2.3 |
| 283 | 239 | 3.3 |
| 288 | 303 | 5.2 |
| 302 | 21 | 0. 1 |
| 364 | 396 | 5. 0 |
| 444 | ?2 | 2.3 |
| 465 | 439 | 6.8 |
| Totals: 13 | 2282 | 33.8 |

RUN 11: 495 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 176 | 44 | 0. 7 |
| 246 | 62 | 1.2 |
| 201 | 157 | 2.0 |
| 2?3 | 47 | 0.7 |
| 468 | 2'73 | 4.4 |
| Totals: 5 | 603 | 9. 0 |

RUN 15: 438 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 82 | 324 | 4.3 |
| 117 | 14$5 | 2.4 |
| 118 | 150 | 2.3 |
| 141 | 46 | 0.5 |
| 143 | 54 | 0.4 |
| 159 | 77 | 1.7 |
| 183 | 15 | 0.1 |
| 216 | 74 | 1.0 |
| 217 | 206 | 3.3 |
| 221 | 8 | C?.1 |
| 223 | 91 | 0.? |
| 226 | 75 | 1.2 |
| 242 | 175 | 2.7 |
| 250 | 26 | 0.2 |
| 251 | 151 | 1.9 |
| 294 | 108 | 1.4 |
| 257 | 46 | 0.5 |
| 244 | 248 | 2.3 |
| 2?1 | 38 | 0.6 |
| 313 | 140 | 1.9 |
| 339 | 16 | 0.6 |
| 343 | 62 | 0.5 |
| 344 | 39 | 0.7 |
| 357 | 33 | 0.3 |
| 397 | 103 | 1.4 |
| 404 | 102 | 1.0 |
| 407 | 45 | 0.6 |
| 41s | 105 | 1.1 |
| 441 | 218 | 3.5 |
| 443 | 16 | 0.1 |
| 445 | 57 | 0.9 |
| 451 | 32 | 0.9 |
| 452 | 42 | 1.2 |
| 453 | 14 | 0.7 |
| 457 | 75 | 0.6 |
| 458 | 146 | 1.3 |
| 464 | 31 | 0.5 |
| 468 | 39 | 0.3 |
| 475 | 121 | 1.? |
| 483 | 90 | 0.9 |
| 494 | 176 | 2.9 |
| 497 | 23 | 0.3 |
| Totals: 42 | 3783 | 51.7 |

RUN 16: 484 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in Oil (hrs) |
|---|---|---|
| 1&8 | 424 | 5.5 |
| 175 | 183 | 2.9 |
| 178 | 3s | Q. 8 |
| 179 | 336 | 5.8 |
| 180 | 332 | 5.7 |
| 185 | 211 | 1.5 |
| 197 | 130 | 2. 5 |
| 258 | 255 | 2. 1 |
| 280 | 123 | 1. 8 |
| 281 | 11 | 0. 4 |
| 283 | 3s | 0.3 |
| 295 | 317 | 4.8 |
| 306 | 512 | 4.8 |
| 317 | 234 | 3. 0 |
| 325 | 101 | 1.2 |
| 332 | 272 | 3.8 |
| Totals: 16 | 3464 | 46. 8 |

RUN 17: 4'?0 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 173 | 121 | 1. 4 |
| 178 | 114 | 1.0 |
| 179 | 36 | 0.6 |
| 204 | 45 | 0.2 |
| 242 | 70 | 0.8 |
| 265 | 363 | 3. 5 |
| 267 | 125 | 1.4 |
| 277 | 252 | 3.6 |
| 285 | 17 | 0.3 |
| 307 | 121 | 1.6 |
| Totals: 10 | 1264 | 14.6 |

RUN 18: 491 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 173 | 24 | 0.6 |
| 180 | 150 | 2.4 |
| 221 | 108 | 0.8 |
| 235 | 93 | 1.8 |
| 273 | 229 | 3.0 |
| 290 | 200 | 2.1 |
| 302 | 225 | 2.[illegible] |
| 326 | 275 | 3.0 |
| 327 | 148 | 4.0 |
| Totals: 9 | 1452 | 20.6 |

RUN 19: 485 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 147 | 96 | 1.0 |
| 184 | 463 | 9.0 |
| 173 | 62 | 0.9 |
| 204 | 161 | 3.2 |
| 205 | 375 | 6.2 |
| 241 | 82 | 1.4 |
| 243 | 276 | 4.9 |
| 258 | 119 | 2.3 |
| 284 | 461 | 5.6 |
| 297 | 285 | 3.8 |
| 301 | 186 | 3.0 |
| 306 | 569 | 7.8 |
| 311 | 144 | 2.1 |
| 320 | 340 | 5.9 |
| 327 | 501 | 5.6 |
| Totals: 15 | 4120 | 62.6 |

RUN 20: 476 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 187 | 158 | 2.9 |
| 188 | 25 | 0.9 |
| 215 | &4 | 0.6 |
| 216 | 63 | 0.5 |
| 219 | 6 | 0.6 |
| 220 | 133 | 1.5 |
| 221 | 74 | 1.0 |
| 225 | 20 | 0.1 |
| 240 | 29 | 1.5 |
| 270 | 32 | 0.8 |
| 273 | 64 | 0.7 |
| 283 | 29 | 0.8 |
| 287 | 37 | 1.2 |
| 288 | 238 | 3.3 |
| 291 | 67 | 0.9 |
| 294 | 22 | 0.4 |
| 323 | 39 | 1.1 |
| 330 | 50 | 0.7 |
| 331 | 11 | 0.4 |
| 364 | 387 | 3.5 |
| 367 | 119 | 1.5 |
| 371 | 322 | 5.0 |
| 396 | 42 | 1.3 |
| 426 | 34 | 0.2 |
| Totals: 24 | 2065 | 31.7 |

Table 13.3 Number of surfacings in oil and time in oiled water for individual gray whale points for each spill scenario at Beaufort site 2 (spring spills) resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 34 gray whales.

RUN 20: 499 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 122 | 84 | 1.8 |
| Totals: | 1 | 84 | 1.8 |

Table ?3.4 Number of surfacings in oil and time in oiled water for individual bowhead whale points for each spill scenario at Beaufort site 2 (summer spills) resulting in whale-ail encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale paint represents 7.6 bowhead whales.

RUN 1: 496 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 298 | 23 | 0.1 |
| 340 | 9 | 0.2 |
| 342 | 70 | 0.8 |
| 422 | 52 | 0.5 |
| Totals: 4 | 154 | 1.7 |

RUN 2: 494 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 19 | 60 | 0.7 |
| 66 | 5 | 0.1 |
| 237 | 35 | 0.4 |
| 337 | 90 | 0.8 |
| 339 | 54 | 0.8 |
| 475 | 22 | 0.& |
| Totals: 6 | 266 | 3.4 |

RUN 3: 441 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 8 | SO | 0.9 |
| 14 | 1 32 | 1. 1 |
| 25 | 41 | 0. & |
| 26 | 74 | 0. 8 |
| 28 | 109 | 1.4 |
| 34 | 47 | 0.4 |
| 38 | 79 | 1. 3 |
| 39 | 50 | 0.9 |
| 42 | 38 | 0. 4 |
| 48 | 84 | 0.6 |
| 5a | 8 | 0.3 |
| 65 | 35 | 0..5 |
| 69 | 60 | c). 7 |
| 79 | 59 | 0.7 |
| 86 | 37 | 0.3 |
| 92 | 12 | 0.4 |
| 96 | 32 | 0.3 |
| 104 | 32 | 1.2 |
| 112 | 16 | 0. 1 |
| 12(J | 52 | 1.2 |
| 138 | 40 | 0.6 |
| 161 | 53 | 1 0 |
| 177 | 81 | 1. 1 |
| 181 | 60 | 0. 6 |
| 194 | 39 | 0. 5 |
| 1 ?9 | 85 | 1.2 |
| 208 | 66 | 0. 5 |
| 209 | 138 | 0. 7 |
| 225 | 38 | 0. 6 |
| 238 | 29 | 0.6 |
| 240 | 39 | t.). 2 |
| 243 | 28 | 0.2 |
| 253 | 19 | 0. 5 |
| 285 | 84 | 0. 8 |
| 298 | 100 | 0.9 |
| 347 | 56 | 0.6 |
| 352 | 5 | 0. 1 |
| 3s7 | 14 | 0.3 |
| 362 | 141 | 1. 6 |
| 364 | 25 | 0. 6 |
| 372 | 107 | 1.3 |
| 375 | 81 | 1. 4 |
| 379 | 1 67 | 1. 1 |
| 386 | 131 | 1. 2 |
| 387 | 102 | 1.0 |
| 390 | 76 | 0. 9 |
| 404 | 133 | 1.0 |
| 406 | 40 | 0.2 |
| 419 | 2 | 0.4 |
| 428 | 45 | 0. & |
| 432 | 17 | 0.2 |
| 443 | 44 | 0.5 |
| 449 | 45 | 0.6 |
| 455 | 45 | 0. 5 |
| 457 | 71 | 1.0 |
| 470 | 91 | 1.0 |
| 474 | 108 | 1. 2 |
| 480 | 43 | 0. 7 |
| 492 | 26 | 0. 4 |
| Totals: 59 | 3561 | 42.6 |

RUN 4: 497 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 81 | 111 | 0.9 |
| | 159 | 101 | 0.5 |
| | 484 | 40 | 0.6 |
| Totals: | 3 | 252 | 2.1 |

RUN 7: 416 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 2 | 41 | 0 7 |
| | 3 | 100 | 1.7 |
| | 14 | 21 | 0 2 |
| | 15 | 37 | 0.4 |
| | 17 | 61 | 0.6 |
| | 21 | 25 | 0 3 |
| | 29 | 33 | 0.4 |
| | 32 | J 85 | 2.0 |
| | 38 | 184 | 2.9 |
| | 43 | 60 | 0 ? |
| | 50 | 17 | 0.1 |
| | 93 | 44 | 0.9 |
| | 54 | 42 | 0 6 |
| | 67 | 360 | 4.9 |
| | 73 | 65 | 0.8 |
| | 79 | 33 | 0.4 |
| | 83 | 45 | 1.1 |
| | 117 | 91 | 2 9 |
| | 118 | 27 | 0 9 |
| | 119 | 216 | 2 0 |
| | 123 | 9s | 1.9 |
| | 130 | 76 | 1.6 |
| | 131 | 38 | 0 4 |
| | 149 | 1 | 0.3 |
| | 132 | 64 | 0.8 |
| | 197 | 164 | 2 1 |
| | 163 | 10 | 0 3 |
| | 170 | 50 | 1.2 |
| | 171 | 56 | 0 6 |
| | 172 | 22 | 0.6 |
| | 183 | 51 | 1.2 |
| | 185 | 132 | 2 2 |
| | 190 | 89 | 1.0 |
| | 193 | 16 | 0 4 |
| | 196 | 118 | 1.7 |
| | 200 | 56 | lb |
| | 204 | 4'4 | 0.9 |
| | 213 | 69 | %.0 |
| | 219 | 129 | 1.3 |
| | 222 | 54 | 0 4 |
| | 227 | 108 | 0 9 |
| | 246 | 91 | 1.0 |
| | 249 | 16 | 0 3 |
| | 2S4 | 10 | 0 3 |
| | 237 | 250 | 3 ? |
| | 264 | 71 | 1 3 |
| | 268 | 27 | 0.8 |
| | 270 | 68 | 0 8 |
| | 271 | 212 | 2 0 |
| | 274 | 161 | 2 6 |
| | 281 | 107 | 1.3 |
| | 282 | 31 | 0.7 |
| | 206 | 143 | 1 6 |
| | 290 | 197 | 2.1 |
| | 291 | 21 | 0.2 |
| | 294 | 57 | 1.3 |
| | 297 | 37 | 0.5 |
| | 326 | 3 | 0.6 |
| | 327 | 92 | 1.6 |
| | 332 | 51 | 0 3 |
| | 335 | 13 | 0.1 |
| | 336 | 59 | 0.7 |
| | 339 | 47 | 0.3 |
| | 359 | 100 | 1.6 |
| | 368 | 99 | 0 6 |
| | 371 | 39 | 0.6 |
| | 370 | 55 | 0 7 |
| | 381 | 195 | 2 2 |
| | 375 | 79 | 0.8 |
| | 379 | 37 | 0 3 |
| | 400 | 136 | 1.6 |
| | 402 | 168 | 1.6 |
| | 414 | 53 | 0 4 |
| | 424 | 110 | 1 4 |
| | 425 | 73 | 0 3 |
| | 431 | 57 | 0 6 |
| | 444 | 53 | 0 7 |
| | 457 | 86 | 1.0 |
| | 460 | 90 | 1.0 |
| | 465 | 6 | 0 2 |
| | 468 | 97 | 1.7 |
| | 471 | 66 | 0.5 |
| | 481 | 123 | 1.'7 |
| | 493 | 40 | 0.4 |
| Totals: | 84 | 6668 | 90.7 |

RUN 8: 480 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 2 | 24 | 0.3 |
| 58 | 30 | 0.5 |
| 63 | 21 | 0.6 |
| 66 | 20 | 0.5 |
| 133 | 22 | 0.6 |
| 177 | 43 | 0.5 |
| 216 | 22 | 0.6 |
| 237 | 39 | 1.0 |
| 238 | 33 | 0.4 |
| 278 | 82 | 1.0 |
| 369 | 72 | 0.8 |
| 380 | 74 | 0.6 |
| Totals: 12 | 482 | 7.7 |

RUN 31: 493 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 74 | 1 | 0.2 |
| 85 | 65 | 0.8 |
| 290 | 80 | 1.0 |
| 306 | 20 | 0.2 |
| 324 | 80 | U.8 |
| 376 | 39 | 0.8 |
| 401 | 107 | 1.2 |
| Totals: 7 | 392 | S.0 |

RUN 12: 495 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 55 | 45 | 0.5 |
| 66 | 44 | 0.9 |
| 97 | 21 | 0.7 |
| 177 | 48 | 0.4 |
| 255 | 27 | 0.5 |
| Totals: 5 | 185 | 3.0 |

RUN 13: 454 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 7 | 19 | 0.7 |
| 16 | 39 | 0.6 |
| 19 | 39 | 0.5 |
| 51 | 1 | 0.4 |
| 54 | 51 | 0.6 |
| 513 | 9 | 0.1 |
| 66 | 43 | 0.4 |
| 91 | 27 | 0.9 |
| 97 | 55 | 0.5 |
| 100 | 68 | 0. a |
| 103 | 62 | 1.2 |
| 108 | 43 | 0.3 |
| 126 | 53 | 0.4 |
| 127 | 74 | 0.3 |
| 153 | 71 | 1.3 |
| 154 | 28 | 0.7 |
| 155 | 72 | 0.8 |
| 163 | 15 | 0.3 |
| 189 | 166 | 1.4 |
| 192 | 79 | 1.3 |
| 194 | 63 | 0.7 |
| 202 | 94 | 0.9 |
| 239 | 24 | 0.5 |
| 255 | 28 | 0.4 |
| 277 | 73 | 0.5 |
| 278 | 37 | 0.9 |
| 304 | 81 | 0.9 |
| 316 | 98 | 0.6 |
| 319 | 55 | 0.7 |
| 325 | 83 | 0.5 |
| 337 | 100 | 0.8 |
| 354 | 45 | 0.6 |
| 379 | 40 | 0.7 |
| 418 | 51 | 0.4 |
| 419 | 146 | 0.8 |
| 432 | 32 | 0.5 |
| 445 | 48 | 0.6 |
| 454 | 118 | 1.8 |
| 458 | 71 | 1.0 |
| 467 | 81 | 0.7 |
| 475 | 34 | 0.6 |
| 479 | 96 | 1.3 |
| 485 | 57 | 0.8 |
| 491 | 51 | 0.8 |
| 492 | 60 | 0.8 |
| 497 | 46 | 0.8 |
| Totals: 46 | 2722 | 33.0 |

RUN 14: 499 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 198 | 58 | 0.7 |
| Totals: 1 | 58 | 0.7 |

RUN 15 382 po ints from a total of S00 points *did* not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 1 | 25 | 0. 6 |
| 3 | 17 | 0.6 |
| 5 | 116 | 1. 5 |
| 6 | 70 | 0 6 |
| 7 | 36 | 0.7 |
| 9 | 13 | 0.2 |
| 12 | 57 | 0. a |
| 14 | 61 | 1. 5 |
| 16 | 22 | 0.9 |
| 19 | 50 | 0.7 |
| 26 | 60 | 0.3 |
| 31 | 88 | 0.8 |
| 34 | 80 | 0.7 |
| 39 | 59 | 0.3 |
| 40 | 96 | 0. 5 |
| 44 | 74 | 0. a |
| 46 | 29 | 0.4 |
| 48 | 77 | 0.9 |
| 49 | 32 | 0.4 |
| 55 | 33 | 0.4 |
| 58 | 140 | z. 4 |
| 61 | 48 | 0.4 |
| 65 | 23 | 0.6 |
| 70 | 21 | 1. 1 |
| 74 | 163 | 1.2 |
| 75 | t 07 | 1. 3 |
| 7? | 58 | 1. 0 |
| 82 | 42 | 0.6 |
| 93 | 60 | 0. 7 |
| 96 | 72 | 0.5 |
| 97 | 62 | 1. 6 |
| 98 | 128 | 1. 7 |
| 100 | 5a | 0. 9 |
| 1 02 | 17 | 0. 5 |
| 113 | 58 | 0.4 |
| 123 | 201 | 3.0 |
| 12s | 217 | 2.9 |
| 130 | 37 | 0.4 |
| 143 | 111 | 1. 5 |
| 149 | 71 | 0. 4 |
| 152 | 183 | 2. 5 |
| 160 | 211 | 2 0 |
| 162 | 2 | 0. 1 |
| 164 | 71 | 0. 6 |
| 165 | 32 | 0. 5 |
| 171 | 167 | 1 3 |
| 172 | 60 | 0 8 |
| 173 | 97 | 0 a |
| 174 | 33 | 0 3 |
| 176 | 32 | 0. 5 |
| 180 | 65 | 0 6 |
| 183 | 84 | 0. 9 |
| 188 | 83 | 0. 9 |
| 192 | 74 | 0 7 |
| 204 | 18 | 0 3 |
| 209 | 38 | 0..4 |
| 213 | 97 | 1.4 |
| 217 | 186 | 2. 2 |
| 219 | 91 | 1.2 |
| 221 | 55 | 0.3 |
| 223 | 132 | I. a |
| 231 | 62 | 1.0 |
| 235 | 95 | 0. 8 |
| 238 | 93 | 0. a |
| 239 | 84 | 0 a |
| 242 | 136 | 2 0 |
| 243 | 6 | 0.1 |
| 255 | 1 | 0.3 |
| 261 | 41 | 0.3 |
| 267 | 86 | 0.7 |
| 269 | 65 | 0. 8 |
| 276 | 139 | 1. 5 |
| 262 | 16 | 0 3 |
| 289 | 76 | 0 8 |
| 270 | 112 | 2. 2 |
| 292 | □s | 1 0 |
| 294 | 29 | 0 3 |
| 303 | 110 | 1. 3 |
| 307 | 76 | 0.7 |
| 311 | 59 | 0.0 |
| 320 | 98 | 1. 1 |
| 325 | 39 | 0 7 |
| 327 | 21 | 0 3 |
| 332 | 23 | 0 3 |
| 335 | 73 | 1. 1 |
| 337 | 59 | 0. 4 |
| 345 | 54 | 1.0 |
| 346 | 57 | 1 0 |
| 348 | 120 | 0 8 |
| 352 | .57 | 0. 9 |
| 35a | 28 | 0.9 |
| 359 | 136 | 1. 6 |
| 362 | 27 | 0 5 |
| 369 | 31 | 0.3 |
| 376 | 88 | 1. 2 |
| 377 | 6a | 0. 9 |
| 383 | 64 | 0. a |
| 386 | 96 | 1 6 |
| 387 | 91 | 0. 9 |
| 401 | 88 | 1.2 |
| 414 | 127 | 1.0 |
| 418 | 49 | 0. 6 |
| 420 | 1 | 0.4 |
| 421 | 40 | 0. 5 |
| 423 | 61 | 0 7 |
| 42a | 54 | 0.4 |
| 429 | 37 | 0. 7 |
| 431 | 40 | 0. 5 |
| 437 | 3 | 0 4 |
| 449 | 16 | 0. a |
| 453 | 72 | 0.0 |
| 458 | 84 | 0. □ |
| 460 | 11 | 0. 5 |
| 472 | 81 | 1.2 |
| 473 | 183 | 2.7 |
| 484 | 71 | 1. 4 |
| 407 | 43 | 1.0 |
| 496 | 21 | 0. 1 |
| Totals: 118 | 8241 | 106. 1 |

Rural 18: 468 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 2 | 51 | c). 5 |
| 8 | 311 | 3.2 |
| 22 | 71 | 0.6 |
| 74 | 44 | 0. & |
| 77 | 27 | 0. 2 |
| 84 | 12 | 0. 3 |
| 117 | 67 | 0. 5 |
| 119 | 1&2 | 3.0 |
| 121 | 37 | 0.3 |
| 133 | 30 | 0.4 |
| 140 | 33 | 0.4 |
| 142 | 54 | 0. 4 |
| 171 | 170 | 1. 8 |
| 179 | 114 | 1.8 |
| 182 | 30 | 0.6 |
| 15'7 | 31 | 0.3 |
| 235 | 87 | 0.5 |
| 244 | 2s' | 0.5 |
| 255 | 37 | 0. 5 |
| 305 | 83 | 0.7 |
| 330 | 15 | 0. 4 |
| 333 | 69 | Q. 8 |
| 334 | 243 | 3.8 |
| 390 | 68 | 0.9 |
| 397 | 53 | 0.5 |
| 412 | 59 | 0. 6 |
| 418 | 62 | 0. 9 |
| 434? | 51 | 0.6 |
| 456 | 18 | 0. 2 |
| 471 | 11 | 0.5 |
| 478 | 10 | 0.5 |
| 489 | 59 | 0.5 |
| **Totals:** 32 | 2198 | 27.3 |

RUN 22: 495 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 55 | 42 | 0.6 |
| 58 | 60 | 0.7 |
| 105 | 51 | U. 7 |
| 313 | 112 | 1.3 |
| 467 | 127 | 1.2 |
| Totals: 5 | 392 | 4.6 |

RUN 25: 465 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 2 | 3 | 0.0 |
| 15 | 135 | 1.6 |
| 16 | 12 | 0.2 |
| 30 | 160 | 1.0 |
| 54 | 43 | 0.5 |
| 55 | 8 | C). 3 |
| 47 | 81 | 1.4 |
| 78 | 25 | 0.7 |
| 101 | 12 | 0.3 |
| 107 | 80 | 1.2 |
| 123 | 16 | C). 3 |
| 129 | 57 | 0.5 |
| 131 | 37 | 0.3 |
| 134 | 61 | 0.6 |
| 135 | 56 | 0.7 |
| 144 | 10 | 0.2 |
| 177 | 94 | 0.7 |
| 184 | 46 | 0.7 |
| 285 | 11 | u. 3 |
| 296 | 55 | C). 5 |
| 333 | 89 | 1.1 |
| 34a | 29 | 0.5 |
| 352 | 48 | C). 7 |
| 365 | 145 | 1.8 |
| 37& | 104 | 1.5 |
| 379 | 95 | 0.9 |
| 382 | 91 | 0.7 |
| 407 | 52 | 1.6 |
| 411 | 71 | 1.1 |
| 419 | 6 | 0.4 |
| 425 | 60 | 0.8 |
| 434 | 17 | 0.3 |
| 494 | 35 | 1.0 |
| 495 | 40 | 0.7 |
| 499 | 30 | 0.8 |
| Totals: 35 | 1922 | 24.9 |

Table B. 5 Number of surfacings in oil and time in oiled water for individual bowhead whale points for each spill scenario at BeauFort site 3 resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 7. 6 bowhead whales.

RUN 1: 499 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 476 | 19 | C?. 5 |
| Totals: 1 | 19 | 0. 5 |

RUN 3: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 5 | 155 | 2. 1 |
| 190 | 64 | 0. 5 |
| Totals: 2 | 2 f'? | 2.6 |

RUN 4: 485 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 21 | 27 | C). 5 |
| 40 | 5 | 0. 1 |
| 47 | 6 | 0. 4 |
| 102 | 14 | 0. 6 |
| 132 | 15 | 0. 1 |
| 147 | 34 | Q. 7 |
| 188 | 94 | 0. 8 |
| 203 | 29 | 0. 7 |
| 215 | 29 | 0. 6 |
| 21(3 | 73 | 0. 9 |
| 355 | 46 | 0. 7 |
| 35s | w | 0. 9 |
| 385 | 53 | 0. 7 |
| 396 | 14 | 0. 2 |
| 439 | 116 | 1. 2 |
| Totals: 15 | & 56 | 9. 1 |

RUN e: 429 points from a total of S00 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 4 | 36 | 0.6 |
| 10 | 20 | 0.6 |
| 20 | 18 | 0.3 |
| 27 | 22 | 0.1 |
| 35 | 7 | 0.1 |
| 44 | 17 | 0.1 |
| 45 | 25 | 0.2 |
| 54 | 10 | 0.1 |
| 58 | 80 | 0.9 |
| 60 | 66 | 0.7 |
| 72 | 51 | 0.4 |
| 74 | 19 | 0.2 |
| 86 | 71 | 0.4 |
| 95 | 19 | 0.3 |
| 97 | 54 | 0.6 |
| 109 | 35 | 0.4 |
| 117 | 120 | 1.4 |
| 126 | 42 | 0.3 |
| 135 | 7 | 1.0 |
| 143 | 56 | 0.7 |
| 132 | 28 | 0.2 |
| 162 | 84 | 0.7 |
| 174 | 19 | 0.6 |
| 173 | 24 | 0.4 |
| 177 | 48 | 0.6 |
| 180 | 95 | 0.9 |
| 185 | 31 | 0.4 |
| 206 | 39 | 0.3 |
| 211 | 8 | 0.3 |
| 220 | 31 | 0.7 |
| 222 | 49 | 0.7 |
| 223 | 41 | 0.7 |
| 227 | 51 | 0.5 |
| 248 | 54 | 0.3 |
| 273 | 15 | 0.2 |
| 278 | 36 | 0.9 |
| 28 1 | 40 | 0.3 |
| 283 | 40 | 0.4 |
| 296 | 79 | 1.3 |
| 2'77 | 83 | 0.6 |
| 301 | 6 | 0.0 |
| 306 | 122 | 0.9 |
| 307 | 30 | 0.5 |
| 309 | 23 | 0.3 |
| 318 | 74 | 1.0 |
| 319 | 31 | 0.7 |
| 323 | 61 | 0.3 |
| 340 | 102 | 0.7 |
| 330 | 8 | 0.4 |
| 354 | 62 | 0.9 |
| 367 | 147 | 1.3 |
| 371 | 17 | 0.9 |
| 379 | 22 | 0.3 |
| 380 | 89 | 0.8 |
| 384 | 11 | 0.2 |
| 397 | 31 | 0.5 |
| 400 | 61 | 0.9 |
| 408 | 103 | 0.6 |
| 413 | 25 | 0.3 |
| 414 | 7 | 0.1 |
| 423 | 102 | 1.0 |
| 433 | 10 | 0.0 |
| 456 | 69 | 0.3 |
| 498 | 63 | 0.7 |
| 464 | 19 | 0.1 |
| 465 | 26 | 0.3 |
| 482 | 30 | 0.2 |
| 487 | 61 | 0.7 |
| 491 | 40 | 0.2 |
| 494 | a | 0.1 |
| 900 | 64 | 0.6 |
| Totals: 71 | 3199 | 36.9 |

RUN 13: 446 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 6 | 20 | 0.7 |
| 13 | 74 | 0.9 |
| 39 | 99 | 1.6 |
| 59 | 99 | 1.0 |
| 65 | 18 | 0.1 |
| 70 | 26 | 0.2 |
| 76 | 70 | 0.8 |
| 7? | 84 | 0.4 |
| 80 | 88 | 1.2 |
| ?0 | 11 | 0.6 |
| ?9 | 21 | 0.4 |
| 103 | 43 | 0.3 |
| 108 | 63 | 0.7 |
| 117 | 149 | 1.7 |
| 119 | 100 | 1.8 |
| 124 | 41 | 0.2 |
| 129 | 59 | 0.7 |
| 130 | 154 | 2.9 |
| 147 | 35 | 0.9 |
| 151 | 95 | 1.3 |
| 162 | 4s | 0.5 |
| 165 | 38 | 0.4 |
| 173 | 52 | 0.9 |
| 17? | 60 | 1.0 |
| 196 | 12 | 0.5 |
| 215 | 44 | 0.8 |
| 223 | 22 | 0.7 |
| 229 | 124 | 0.7 |
| 245 | 29 | 0.7 |
| 2s0 | 40 | 0.6 |
| 260 | 46 | 0.5 |
| 261 | 32 | 0.9 |
| 271 | 48 | 0.5 |
| 281 | 50 | 0.3 |
| 321 | 54 | 0.8 |
| 327 | 13 | 0.2 |
| 339 | 80 | 0.8 |
| 338 | 61 | 0.8 |
| 339 | 46 | 0.6 |
| 352 | 42 | 0.4 |
| 3s7 | 61 | 0.6 |
| 360 | 17 | 0.5 |
| 362 | 6 | 0.3 |
| 379 | 70 | 0.9 |
| 381 | 4 | 0.3 |
| 386 | 39 | 0.7 |
| 399 | 17 | 0.1 |
| 404 | 84 | 0.7 |
| 420 | 47 | 0.5 |
| 441 | 42 | 1.0 |
| 445 | 6 | 0.2 |
| 453 | 23 | 0.3 |
| 485 | 73 | 0.7 |
| 49a | 33 | 0.a |
| Totals: 54 | 2808 | 38.4 |

RUN 14: 494 points from a total of 54X) points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 27 | 47 | 0.7 |
| 30 | 42 | 0.5 |
| 86 | 88 | 0.9 |
| 169 | 1 | 0.3 |
| 368 | 84 | 0.9 |
| 385 | 3 | 0.5 |
| Totals: 6 | 265 | 3.8 |

RUN 15: 491 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 8 | 53 | 0.8 |
| 92 | 14 | 0.3 |
| 152 | 37 | 0.8 |
| 1'92 | 17 | 0.3 |
| 220 | 34 | C?. 4 |
| 342 | 16 | 0.1 |
| 446 | 56 | 0.6 |
| 467 | 33 | 0.3 |
| 477 | 66 | 0.B |
| Totals: 9 | 326 | 4.4 |

RUN 17: 494 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 90 | 78 | 0.8 |
| 281 | 49 | 0.3 |
| 304 | 73 | 0.4 |
| 313 | 19 | 0.4 |
| 339 | 37 | 0.5 |
| 344 | 20 | 0.6 |
| Totals: 6 | 276 | 3.4 |

RUN 1S: 496 points from a total of 500 points did not hit oil.

| Whale pt II) # | # of hits | Time in oil (hrs) |
|---|---|---|
| 256 | 103 | 0.9 |
| 266 | 255 | 2.6 |
| 299 | 24 | 0.7 |
| 477 | 59 | 1.2 |
| **Totals:** 4 | 441 | S. 4 |

RUN 1'7: 468 points from a total of 500 points did not hit oil.

| Whale pt ID # | # OF hits | Time in oil (hrs) |
|---|---|---|
| 1 | 13 | 0.2 |
| 32 | 48 | C). 3 |
| 89 | 92 | 0.7 |
| 119 | 38 | 0.4 |
| 148 | 18 | 0.5 |
| 153 | 34 | 0.7 |
| 154 | 50 | 0.4 |
| 1=3 | 45 | 0.7 |
| 186 | 21 | 0.1 |
| 194 | 65 | 0.6 |
| 15'7 | 38 | 0.7 |
| 216 | 39 | 0.6 |
| 242 | 13 | 0.2 |
| 250 | 94 | 1.1 |
| 284 | 194 | 1.7 |
| 295 | 83 | 1.6 |
| 306 | 15 | 0.2 |
| 314 | 75 | 1.4 |
| 323 | 52 | 0.8 |
| 334 | 62 | 0.& |
| 367 | 24 | 0.5 |
| 390 | 38 | 0.8 |
| 394 | 45 | 1.3 |
| 419 | 7 | 0.5 |
| 426 | 83 | 0.0 |
| 437 | 91 | 1.0 |
| 448 | 52 | 0.3 |
| 4S2 | 32 | 0.6 |
| 454 | 39 | 0.3 |
| 472 | 64 | 0.8 |
| 481 | 30 | 0.3 |
| 494 | 27 | 0.9 |
| Totals: 32 | 1621 | 21.6 |

RUN 20: 449 points from a total of 500 points did not hit oil.

| Whale pt ID #" | # of hits | Time in Oil (hrs) |
|---|---|---|
| 5 | 61. | 0.6 |
| 12 | 90 | 0.5 |
| 18 | 106 | 1. 2 |
| 40 | 26 | 0.3 |
| 47 | 34 | 0.8 |
| 56 | 83 | 1.6 |
| 69 | 119 | 1. 2 |
| 84 | 58 | 0.7 |
| 87 | 62 | 0.7 |
| 96 | 9a | 1. 0 |
| 115 | 90 | 1.3 |
| 116 | 92 | 1.2 |
| 123 | 72 | 1.3 |
| 142 | 52 | 0.6 |
| 150 | 60 | 1.0 |
| 1 63 | 50 | 1.0 |
| 175 | 24 | 0.6 |
| 182 | 47 | 0. '7 |
| 191 | 50 | 0.5 |
| 198 | 57 | 0.9 |
| 212 | 103 | 0.8 |
| 230 | 24 | 0.3 |
| 233 | 4a | 0.-7 |
| 241 | 62 | 1. 1 |
| 242 | 50 | 0. 6 |
| 247 | a | 0. 5 |
| 249 | 79 | 1.4 |
| 252 | 79 | 1.0 |
| 264 | 70 | 0.6 |
| 268 | 17 | 0.7 |
| 276 | 79 | 0'? |
| 284 | 56 | 0. 6 |
| 297 | 132 | 1. 2 |
| 293 | 117 | 1. 9 |
| 319 | 64 | 0. 5 |
| 324 | 47 | 0. 5 |
| 358 | 75 | 1.0 |
| 362 | 13 | 0.2 |
| 376 | 66 | 1.0 |
| 392 | 34 | 0. 4 |
| 409 | 16 | 0.4 |
| 431 | 20 | 0.4 |
| 434 | 45 | 0. a |
| 446 | 95 | 1. 5 |
| 450 | 4 | 0.2 |
| 459 | 37 | 0.6 |
| 462 | 77 | 1.2 |
| 464 | 57 | 0.4 |
| 481 | 23 | 0. 1 |
| 495 | 103 | 1. 8 |
| 49a | 46 | 0.5 |
| Totals: 51 | 3079 | 41.5 |

RUN 22: 439 points from a total of 500 points did not hit oil

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 1 | 60 | 0.5 |
| 12 | 37 | 0.5 |
| 24 | 90 | 0.6 |
| 33 | 56 | 0.4 |
| 42 | 88 | 1.0 |
| 60 | 86 | 1.1 |
| 77 | 146 | 1.2 |
| 82 | 24 | 0.2 |
| 83 | 32 | 0.8 |
| 102 | 30 | 0.4 |
| 113 | 45 | 0.6 |
| 119 | 90 | 0.9 |
| 134 | 118 | 1.5 |
| 135 | 10.2 | 0.9 |
| 143 | 31 | 1.3 |
| 14-4 | 29 | 0.4 |
| 158 | 56 | 1.0 |
| 167 | 46 | 0.8 |
| 173 | 23 | 0.3 |
| 17? | 36 | 0.7 |
| 199 | 93 | 1.5 |
| 197 | 2a | 0.5 |
| 203 | 34 | 0.2 |
| 220 | 100 | 1.1 |
| 223 | 82 | 1.3 |
| 238 | 38 | 0.4 |
| 249 | 34 | 0.6 |
| 25? | 53 | 0.7 |
| 263 | 18 | 0.1 |
| 274 | 126 | 1.4 |
| 285 | 111 | 2.1 |
| 286 | 102 | 0.9 |
| 295 | 121 | 1.2 |
| 297 | 49 | 0.6 |
| 303 | 24 | 0.6 |
| 309 | 87 | 0.6 |
| 315 | 55 | 0.6 |
| 31s | 63 | 0.8 |
| 322 | 99 | 1.4 |
| 329 | 59 | 0.8 |
| 326 | 55 | 0.9 |
| 330 | 22 | 0.2 |
| 350 | 85 | 0.7 |
| 352 | 68 | 0.8 |
| 357 | 32 | 0.7 |
| 35? | 77 | 0.a |
| 364 | 53 | 0.7 |
| 384 | 76 | 1.7 |
| 416 | 64 | 1.0 |
| 421 | 162 | 1.5 |
| 436 | 22 | 0.9 |
| 438 | 63 | 0.4 |
| 460 | 56 | 0.6 |
| 47a | 118 | 1.0 |
| 481 | 103 | 0.7 |
| 405 | 30 | 0.7 |
| 487 | 47 | 0.6 |
| 489 | 33 | 0.5 |
| 491 | 119 | 1.0 |
| 494 | 50 | 1.9 |
| 496 | 100 | 0.9 |
| Totals: 61 | 4064 | 50.7 |

RUN 23: 463 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 25 | 18 | 0.4 |
| 26 | 96 | 0.7 |
| 28 | 62 | 0.4 |
| 42 | 55 | 0.7 |
| 48 | 94 | 1.0 |
| 51 | 12 | 0.3 |
| 78 | 14kl | C).9 |
| 82 | 9s | 1.3 |
| 96 | 41 | 0.6 |
| 102 | 23 | 0.6 |
| 151 | 22 | c).6 |
| 1'57 | 87 | i.2 |
| 175 | 91 | 1.0 |
| 197 | 83 | 0.7 |
| 201 | 22 | C).5 |
| 205 | 12 | Q.2 |
| 212 | 36 | 0.4 |
| 230 | 20 | 0.5 |
| 236 | 52 | 1.0 |
| 238 | 59 | 0.7 |
| 25S | 27 | 0.5 |
| 285 | 38 | 0.6 |
| 302 | 34 | 0.5 |
| 30 5 | 28 | 0.6 |
| 345 | 28 | 0.5 |
| 340 | 105 | 1.5 |
| 373 | 49 | 0.5 |
| 379 | 70 | 1.0 |
| 383 | 38 | 0.7 |
| 392 | 46 | #.9 |
| 402 | 145' | 1.9 |
| 433 | 49 | 0.8 |
| 449 | 51 | 0.8 |
| 452 | 82 | 1.3 |
| 470 | 68 | 0.5 |
| 488 | 15 | Q.5 |
| 492 | 93 | #.7 |
| Totals: 37 | 205'4 | 27.5 |

RUN 24: 450 points from a total of 500 points did not hit oil

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 9 | 40 | 0.6 |
| 17 | 03 | 1.2 |
| 36 | 21 | 0.2 |
| 45 | 124 | 2.0 |
| 50 | 49 | 0.6 |
| 54 | 45 | 0.9 |
| 62 | 34 | 0.7 |
| 65 | 65 | 1.0 |
| 71 | 56 | 0.4 |
| 73 | 45 | 0.4 |
| 83 | 82 | 0.9 |
| 04 | 47 | 0.6 |
| 89 | 112 | 1.0 |
| 94 | 73 | 0.5′ |
| 113 | 57 | 0.7 |
| 118 | 76 | 1.0 |
| 124 | 43 | 0.5 |
| 138 | 25 | 0.5 |
| 154 | 16 | 0.5 |
| 156 | 95 | 1.1 |
| 168 | 70 | 1.1 |
| 170 | 9 | 0.2 |
| 174 | 196 | 2.7 |
| 186 | 51 | 0.9 |
| 188 | 3 4 | 1.1 |
| 196 | 62 | 1.2 |
| 206 | 33 | 1.0 |
| 220 | 47 | 0.8 |
| 239 | 70 | 0.B |
| 248 | 10 | 0.4 |
| 260 | 65 | 0.6 |
| 262 | 88 | 0.8 |
| 264 | 32 | 1.2 |
| 272 | 85 | 0.6 |
| 294 | 103 | 0.5 |
| 303 | 36 | 0.6 |
| 345 | 18 | G.7 |
| 346 | 100 | 1.2 |
| 372 | 76 | 0.8 |
| 381 | 124 | 0.9 |
| 391 | 40 | 0.4 |
| 398 | 22 | 0.5 |
| 408 | 66 | 0.7 |
| 437 | 88 | 0.9 |
| 439 | 25 | 0.7 |
| 442 | 19 | 0.2 |
| 468 | 87 | 0.8 |
| 487 | 32 | 0.7 |
| 490 | 181 | 1.3 |
| 491 | 42 | 0.8 |
| **Totals:** 50 | 3099 | 40.8 |

RUN 25: 498 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 365 | 119 | 1.0 |
| | 500 | 51 | 0.9 |
| Totals: | 2 | 170 | 1.9 |

Table B. 6 Number of surfacings in oil and time in oiled water for individual bowhead whale points for each spill scenario at Beaufort site 4 resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 7. & bowhead whales.

RUN 5: 480 points from a total of 500 points did not hit oil.

| Whale pt II) # | # of hits | Time in oil (hrs) |
|---|---|---|
| 8 | 323 | 4.0 |
| 86 | 157 | 2.0 |
| 128 | 143 | 1. 2 |
| 1 42 | 343 | 3.8 |
| 150 | 540 | 6.4 |
| 252 | 458 | 5.4 |
| 275 | 880 | 12.7 |
| 279 | 28 | 0. 4 |
| 207 | 215 | 3.6 |
| 301 | 178 | 2.7 |
| 302 | 97 | 1.2 |
| 341 | 153 | 2.4 |
| 353 | 73 | 1.5 |
| 359 | 296 | 4. 4 |
| 370 | 105 | 0. 9 |
| 385 | 65 | 2.0 |
| 393 | 266 | 4. 2 |
| 410 | 130 | 2. 1 |
| 453 | 24 | 0. 7 |
| 462 | 164 | 1.6 |
| Totals: 20 | 4638 | 63.6 |

RUN 9: 499 points from a total of 500 points did not hit *oil.*

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 446 | 251 | 3.7 |
| Totals: 1 | 251 | 3.7 |

RUN 12: 487 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 32 | 89 | 1.8 |
| 35 | 55 | 1.2 |
| 64 | 83 | 1.4 |
| 121 | 164 | 1.4 |
| 170 | 156 | 1.2 |
| 171 | 130 | 1.7 |
| 210 | 118 | 1.4 |
| 276 | 64 | 1.5 |
| 350 | 32 | 0.5 |
| 390 | 121 | 1.7 |
| 393 | 15 | 1.0 |
| 450 | 129 | 0.9 |
| 405 | 174 | 1.8 |
| Totals: 13 | 1330 | 17.5 |

RUN 13: 427 points from a total of [illegible] points [illegible]

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 5 | 114 | 1.1 |
| 8 | 166 | 2.4 |
| 9 | 123 | 2.0 |
| 11 | 139 | 1.4 |
| 12 | 180 | 1.4 |
| 16 | 188 | 3.0 |
| 31 | 104 | 1.4 |
| 33 | 262 | 3.6 |
| 39 | 83 | 0.5 |
| 43 | 127 | 2.2 |
| 46 | 75 | 1.4 |
| 54 | 221 | 4.0 |
| '50 | 41 | 0.3 |
| 64 | 45 | 0.5 |
| 66 | 283 | 3.3 |
| 7a | 95 | 1.7 |
| El | 7a | 0.6 |
| 84 | 111 | 2.2 |
| 86 | 249 | 3.2 |
| 89 | 392 | 5.0 |
| 111 | 333 | 3.4 |
| 124 | 19 | 1.3 |
| 125 | 162 | 3.7 |
| 136 | 18 | 0.5 |
| 151 | 166 | 1.4 |
| 157 | 191 | 2.7 |
| 199 | 108 | 1.1 |
| 173 | 110 | 1.7 |
| 190 | 154 | 1.9 |
| 200 | 183 | 2.4 |
| 206 | 28 | 0."7 |
| 207 | 75 | 1.5 |
| 210 | 145 | 2.8 |
| 214 | 175 | 2.1 |
| 219 | 9s | 1.1 |
| 229 | 9a | 1.4 |
| 232 | 412 | 5.8 |
| 237 | 137 | 0.7 |
| 238 | 61 | 1.4 |
| 249 | 85 | 1.1 |
| 255 | 269 | 2.6 |
| 266 | 13'4 | 2.6 |
| 272 | 37 | 0.8 |
| 282 | 272 | 2.6 |
| 293 | 221 | 1.6 |
| 298 | 68 | 2.2 |
| 304 | 46 | 1.1 |
| 309 | 69 | 1.3 |
| 318 | 86 | 0.9 |
| 321 | 5a | 0.7 |
| 343 | 187 | 2.4 |
| 358 | 183 | 2.4 |
| 361 | 86 | 1.3 |
| 363 | 15 | 0.7 |
| 374 | 93 | 1.1 |
| 377 | 17 | 0.a |
| 385 | 84 | 1.5 |
| 388 | 91 | 1.0 |
| 394 | 13 | 0.4 |
| 401 | 279 | 3.4 |
| 403 | 46 | 0.8 |
| 404 | 41 | 0.B |
| 414 | 107 | 1.3 |
| 417 | 266 | 3.7 |
| 421 | 179 | 2.3 |
| 425 | 94 | 1.4 |
| 430 | 249 | 3.9 |
| 435 | 126 | 2.2 |
| 43a | 2a | 0.7 |
| 459 | 121 | 1.9 |
| 466 | 67 | 0.4 |
| 472 | 151 | 2.4 |
| 473 | 239 | 2.7 |
| Totals: 73 | 9872 | 135.a |

RUN 14: 484 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 18 | 275 | 4.7 |
| 149 | 371 | 5.0 |
| 284 | 220 | 3.8 |
| 29a | 162 | 2.3 |
| 322 | 317 | 3.7 |
| 347 | 32 | 1.0 |
| 349 | 553 | 9.0 |
| 396 | 423 | 5.3 |
| 408 | 50 | 0.4 |
| 421 | 179 | 2.2 |
| 426 | 187 | 2.0 |
| 429 | 533 | 7.3 |
| 439 | 555 | 8.6 |
| 469 | 365 | 5.7 |
| 470 | 13 | 0.4 |
| 477 | 39 | 0.6 |
| Totals: 16 | 4274 | 152.0 |

RUN 15: 484 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 104 | 150 | 2.5 |
| 123 | 299 | 5.0 |
| 125 | 266 | 2.5 |
| 146 | 65 | 1.1 |
| 221 | 66 | 0.8 |
| 258 | 159 | 2.7 |
| 300 | 239 | 3.1 |
| 309 | 301 | 5.0 |
| 424 | 157 | 1.? |
| 437 | 400 | 5.7 |
| 440 | 367 | 4.5 |
| 462 | 367 | 4.9 |
| 465 | 153 | 2.2 |
| 493 | 68 | 0.7 |
| 495 | 279 | 3.9 |
| 500 | 84 | 1.4 |
| Totals: 16 | 3420 | 47.a |

RUN 16: 469 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 12 | 460 | 6.2 |
| 23 | 45 | 0.9 |
| 33 | 8 | 0.3 |
| 35 | 314 | 4.8 |
| 51 | 2a | 0.2 |
| 54 | 37 | 0.5 |
| 62 | 406 | S.9 |
| 74 | 150 | 1.6 |
| 84 | 348 | 5.1 |
| 88 | 352 | 4.1 |
| 97 | 5'7 | 1.0 |
| 127 | 228 | 2.8 |
| 132 | 18 | 0.3 |
| 134 | 116 | 1.3 |
| 135 | 243 | 3.2 |
| 145 | 37 | 0.5 |
| 227 | 126 | 1.8 |
| 241 | 13 | 0.2 |
| 269 | 72 | 2.0 |
| 274 | 561 | 7.3 |
| 291 | 863 | 11.1 |
| 310 | 177 | 2.1 |
| 317 | 151 | 4.1 |
| 340 | 564 | 8.5 |
| 363 | 1 07 | 1.2 |
| 384 | 340 | 4.5 |
| 38 5 | 190 | 3.9 |
| 399 | 35 | 0.4 |
| 419 | 78 | 1.0 |
| 423 | 114 | 1.4 |
| 456 | 111 | 1.6 |
| Totals: 31 | 6385' | 89.7 |

RUN 17: 456 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 1 | 303 | 4.0 |
| 15 | 34 | 0.6 |
| 35 | 318 | 4.3 |
| 53 | 97 | 1.6 |
| 62 | 160 | 2.5 |
| 67 | 455 | S. 3 |
| 90 | 564 | 7.8 |
| 117 | 64 | 1.9 |
| 132 | 146 | 2. 4 |
| 134 | 7 | 0. 1 |
| 141 | 67 | 1.4 |
| 149 | 73 | 1.0 |
| 182 | 149 | 1. 5 |
| 1 94 | 38 | 0.6 |
| 200 | 228 | 3.2 |
| 212 | 35 | 0. 7 |
| 214 | 129 | 1. 6 |
| 21? | 117 | 2. 1 |
| 223 | 124 | 2. S |
| 245 | 91 | 1. 8 |
| 253 | 42 | 0. 6 |
| 283 | 141 | 2. 2 |
| 285 | 99 | 2. 2 |
| 287 | 406 | 5. 1 |
| 29? | 90 | 0.7 |
| 322 | 1 #2 | 1. 5 |
| 330 | 333 | 5. 6 |
| 334 | 306 | 3.4 |
| 338 | 258 | 4'.4 |
| 349 | 148 | 2. 1 |
| 350 | 159 | 2.0 |
| 359 | 111 | 2.0 |
| 367 | 68 | 1.9 |
| 395 | 687 | 8. 0 |
| 403 | 55'3 | 5. 8 |
| 405 | 60 | 0. 8 |
| 416 | 224 | 2. 1 |
| 427 | 13= | 2. 1 |
| 437 | 94 | 1.7 |
| 459 | 173 | 1.7 |
| 463 | 573 | 7.4 |
| 470 | 160 | 3.0 |
| 481 | 429 | 5. 3 |
| 484 | 545 | 8. 1 |
| Totals: 44 | 9138 | 127.7 |

RUN 18· 384 points from a total of 500 points did not hit oil

| Whale pt ID # | # of hits | Time in oil (hrs ) |
|---|---|---|
| [illegible] | 152 | 3.2 |
| 8 | 171 | 2.2 |
| 10 | 278 | 3 2 |
| 19 | 207 | 2 1 |
| 34 | 171 | 2.5 |
| 41 | 234 | 2.9 |
| 52 | 541 | 6 2 |
| 54 | 271 | 3 0 |
| 60 | 306 | 4 1 |
| 61 | [illegible] | 0 2 |
| 62 | 1 48 | 2 1 |
| 63 | 14 | 0.4 |
| 64 | 52 | 1.0 |
| 65 | 111 | 1.9 |
| 73 | 206 | 3 5 |
| 84 | 166 | 2 5 |
| 88 | 183 | 2.8 |
| 98 | 50 | 0.5 |
| 110 | 110 | 2.0 |
| 111 | 349 | 3.7 |
| 121 | 128 | 1.2 |
| 1 26 | 81 | 1.0 |
| 142 | ! 97 | 3.0 |
| 151 | 147 | 1.5 |
| 132 | 107 | 1 6 |
| t 54 | 132 | 2 7 |
| 156 | 14 | 0 3 |
| 162 | 97 | 1 4 |
| 164 | 66 | 0.5 |
| 167 | 64 | 0.8 |
| 171 | 195 | 1.8 |
| 172 | 398 | 5.4 |
| 173 | 231 | 3 2 |
| 1 80 | 123 | 2.3 |
| 184 | 42a | 5.4 |
| 1 85 | 17 | 0 2 |
| 192 | 120 | 1.2 |
| 193 | 247 | 4 2 |
| 203 | 24 5 | 3.0 |
| 205 | 79 | 0.6 |
| 208 | 46 | 1.5 |
| 212 | 92 | 1 7 |
| 214 | 71 | 1.7 |
| 219 | 90 | 2 3 |
| 223 | ?s2 | 4.7 |
| 227 | 26 | 0 1 |
| 228 | 96 | 1.5 |
| 229 | 202 | 2.8 |
| 239 | 173 | 3 3 |
| 241 | 308 | 3 0 |
| 242 | 92 | 1 9 |
| 249 | 29 | 0 7 |
| .251 | 120 | 2 7 |
| 253 | 673 | 8.1 |
| 256 | 104 | 1 3 |
| 267 | 547 | 7.5 |
| 268 | 71 | 1.1 |
| 272 | 406 | 6.1 |
| 2?4 | 87 | 1.4 |
| 275 | 487 | 6.2 |
| 277 | 48 | 0.6 |
| 278 | 289 | 3 0 |
| 282 | 159 | 1.8 |
| 283 | 404 | 3 8 |
| 284 | 1?7 | 2.2 |
| 207 | 1'?2 | 2.7 |
| 298 | 405 | 9 3 |
| 30 [ | .?77 | 3.8 |
| 302 | 115 | 1 7 |
| 303 | 121 | 1 7 |
| 322 | 187 | 2 8 |
| 325 | 291 | 3.8 |
| 329 | 279 | 4 6 |
| 344 | 525 | 8 3 |
| 345 | 436 | 7 0 |
| 346 | 151 | 2.2 |
| 348 | 10? | 2 3 |
| 354 | 278 | 3 3 |
| 358 | 338 | 3 6 |
| 36 1 | 163 | 3 1 |
| 372 | 368 | 5.6 |
| 3?4 | 55 | 1 0 |
| 37B | 84 | 1.9 |
| 379 | 92 | 1 4 |
| 380 | 347 | 4 3 |
| 382 | 95 | 1.2 |
| 393 | 30.7 | 3 ? |
| 395 | 245 | 3 5 |
| 401 | 256 | 3 3 |
| 402 | 373 | 3 4 |
| 403 | 394 | 5 1 |
| 404 | 293 | 3.3 |
| 406 | 122 | 2.2 |
| 407 | 1.52 | 2. 7 |
| 414 | 92 | 1.8 |
| 415 | 33s | 5 1 |
| 418 | 144 | 2 3 |
| 423 | 165 | 2.4 |
| 426 | 1 .52 | 1 5 |
| 434 | 324 | 3.7 |
| 436 | 133 | 1.8 |
| 441 | 61 | 1 2 |
| 442 | 365 | 5 2 |
| 448 | 614 | 7 1 |
| 450 | 147 | 2 5 |
| 453 | 367 | 5.3 |
| 456 | 382 | 5.6 |
| 457 | 280 | 3.2 |
| 460 | 232 | 3 8 |
| 469 | 44 | 0 8 |
| 471 | 352 | 4 3 |
| 474 | 146 | 2 7 |
| 47 7 | 335 | 5.7 |
| 480 | 233 | 4.8 |
| 485 | 291 | 4 3 |
| 489 | 166 | 3.4 |
| Totals: 116 | 24394 | 341.9 |

RUN 21: 439 points from a total of 500 points did nut hit oil.

| Whale ot ID #r | # of hits | Time in oil (hrs) |
|---|---|---|
| 10 | 354 | 5.9 |
| 36 | 272 | 5.4 |
| 46 | 224 | .3. 5 |
| 47 | 534 | 6.8 |
| 53 | 111 | 1. 1 |
| 56 | 157 | 2. 1 |
| 62 | 352 | 4.9 |
| 74 | 207 | 1. 8 |
| 77 | 509 | 5. 8 |
| 78 | 176 | 2.4 |
| 84 | 217 | 3. 1 |
| 85 | 156 | 3.0 |
| 86 | 357 | 5. S |
| 93 | 281 | 4.4 |
| 98 | 1&3 | 2. 6 |
| 114 | 328 | 3.4 |
| 128 | 191 | 2.5 |
| 145 | 62 | 0. 5 |
| 14? | 113 | 2.0 |
| 155 | 385 | 5.8 |
| 162 | 230 | 2. 9 |
| 176 | 363 | 3.7 |
| 182 | 241 | 3.4 |
| 188 | 50 | 1. 7 |
| 189 | 261 | 3.3 |
| 193 | 95 | 1.2 |
| 212 | 386 | 4.7 |
| 244 | 223 | 3. S |
| 248 | 90 | 1.2 |
| 251 | 302 | 3. 5 |
| 253 | 236 | 5.4 |
| 254 | 382 | 6. 5 |
| 258 | 383 | 6. 0 |
| 269 | 393 | 7.0 |
| 285 | 614 | 8. 8 |
| 307 | 314 | 5. 1 |
| 325 | 133 | 2. 1 |
| 329 | 229 | 2.9 |
| 331 | 144 | 2.0 |
| 335 | 213 | 3.4 |
| 338 | 65 | 1. 5 |
| 342 | 338 | 4.3 |
| 359 | 30 7 | 4.6 |
| 360 | 148 | 1.9 |
| 369 | 280 | 3.2 |
| 374 | 257 | 2.4 |
| 382 | 103 | 1. 1 |
| 383 | 770 | 13.6 |
| 390 | 75 | 0. 9 |
| 402 | 176 | 2.4 |
| 420 | 193 | 2.6 |
| 427 | 274 | 3.7 |
| 450 | 178 | 2.4 |
| 468 | 159 | 2. & |
| 469 | 221 | 2.7 |
| 478 | 189 | 3.2 |
| 481 | 116 | 1.8 |
| 403 | 483 | 7.2 |
| 494 | 133 | 1. 8 |
| 495 | 477 | 7.9 |
| 499 | 76 | 1.0 |
| Totals: 61 | 1 554? | 220. 5 |

RUN 22: 480 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 18 | 199 | 1.7 |
| 126 | 16 | 0.1 |
| 168 | 114 | 1.5 |
| 218 | 265 | 3.1 |
| 241 | 207 | 2.8 |
| 246 | 315 | 4.8 |
| 282 | 24 | 0.7 |
| 284 | 250 | 4.3 |
| 308 | 283 | 4.8 |
| 325 | 375 | 5.6 |
| 353 | 268 | 2.6 |
| 364 | 554 | 7.8 |
| 393 | 201 | 3.5 |
| 406 | 230 | 3.3 |
| 438 | 124 | 1.1 |
| 464 | 861 | 12.5 |
| 465 | 145 | 1.6 |
| 468 | 639 | 9.0 |
| 4s 1 | 3s 1 | 5.0 |
| 486 | 128 | 1.9 |
| Totals: 20 | 5580 | 77.9 |

RUN 23: 462 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 4 | 107 | 2.9 |
| 85 | 233 | 3.2 |
| 89 | 189 | 2.2 |
| 94 | 311 | 5.2 |
| 111 | 198 | 3.7 |
| 121 | 284 | 3.2 |
| 130 | 123 | 1.3 |
| 150 | 142 | 2.0 |
| 153 | 192 | 2.1 |
| 162 | 115 | 2.3 |
| 179 | 310 | 4.3 |
| 109 | 489 | 7.6 |
| 204 | 56 | 0.9 |
| 206 | 113 | 2.3 |
| 217 | 5 | 0.4 |
| 226 | 51 | 1.3 |
| 22? | 21 | C?.4 |
| 244 | 129 | 1.8 |
| 245 | 397 | 5.6 |
| 2S7 | 118 | 1.6 |
| 272 | 96 | 1.5 |
| 2%7 | 157 | 3.1 |
| 292 | 102 | 0.8 |
| 319 | 1603 | 24.0 |
| 334 | 94 | 0.8 |
| 354 | 81 | 1.9 |
| 356 | 218 | 3.0 |
| 394 | 516 | 5.8 |
| 39'7 | 124 | 2.0 |
| 419 | 78 | 1.1 |
| 442 | 80 | 1.0 |
| 454 | 574 | 7.9 |
| 458 | 25 | 0.3 |
| 464 | 257 | 3.5 |
| 469 | 319 | 4.5 |
| 470 | 560 | 7.7 |
| 481 | 120 | 1.8 |
| 482 | 1550 | 23.2 |
| Totals: 38 | 10137 | 148.4 |

RUN 25: 499 points f-rem a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 265 | 54 | 0.5 |
| Totals: 1 | 54 | 0.5 |

Table B.7 Number of surfacings in oil and time in oiled water for individual bowhead whale points for each spill scenario at Beaufort site 5 (spring spills) resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale paint represents 7.6 bowhead whales.

RUN 1: 497 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 258 | 85 | 1.1 |
| | 271 | 70 | 0.6 |
| | 283 | 71 | 1.2 |
| Totals: | 3 | 226 | 2.9 |

RUN 16: 481 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 172 | 105 | 1.0 |
| | 174 | 10 | 0.3 |
| | 179 | 172 | 1.5 |
| | 185 | 38 | 0.5 |
| | 194 | 85 | 1.3 |
| | 204 | 34 | 0.4 |
| | 205 | 2? | 0.5 |
| | 214 | 61 | 0.4 |
| | 221 | 25 | C).4 |
| | 224 | 21 | 0.5 |
| | 235 | 68 | 0.9 |
| | 2S4 | 7 | u.2 |
| | 256 | 97 | 1.0 |
| | 263 | 73 | 0.7 |
| | 283 | 23 | 0.4 |
| | 292 | 45 | 0.4 |
| | 295 | 71 | 0.5 |
| | 309 | 1 | 0.2 |
| | 324 | 62 | 1.0 |
| Totals: | 19 | 1027 | 12.1 |

RUN 17: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 283 | 55 | 0.4 |
| 383 | 22 | 0.4 |
| Totals: 2 | 77 | 0.8 |

RUN 21: 486 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 16s | 39 | 0.3 |
| 174 | 70 | 1.2 |
| 179 | 246 | 2.4 |
| 205 | 40 | 0.3 |
| 221 | 44 | 0.4 |
| 235 | 216 | 2.2 |
| 249 | 98 | 1.1 |
| 269 | 31 | C?.5 |
| 283 | 4 | 0.3 |
| 285 | 24 | 1.1 |
| 290 | 170 | 1.7 " |
| 292 | 49 | 0.3 |
| 306 | 232 | 2.1 |
| 317 | 13 | 0.1 |
| Totals: 14 | 1276 | 14.0 |

RUN 22: 490 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 179 | 40 | 0.4 |
| 220 | 182 | 1.9 |
| 221 | 1 | 0.0 |
| 235 | 60 | 0.3 |
| 273 | 2%3 | 2.5 |
| 290 | 78. | 1.2 |
| 306 | 133 | 1.6 |
| 327 | 2% | 0.3 |
| 329 | 85 | 2.2 |
| 332 | 1 00 | 0.7 |
| Totals: 10 | 990 | 11.1 |

**Table B.8** Number of surfacings in oil and time in oiled water for individual gray whale points for each spill scenario at Beaufort site 5 (spring spills) resulting in whale-oil encounters. **Values are calculated at 10 days after the last oil release.** Note that results are presented for whale points: each whale point represents 34 gray whales.

RUN 16: 4'?9 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 315 | 119 | 3.2 |
| Totals: 1 | 119 | 3.2 |

Table B.9 Number of surfacings in oil and time in oiled water for individual bowhead whale points for each spill scenario at Beaufort site 5 (summer spills) resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 7. 6 bowhead whales.

RUN 1: 47S points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 17 | 41 | 0.4 |
| | 37 | 30 | 0.7 |
| | 53 | 42 | 0.6 |
| | 57 | 65 | 0.8 |
| | 68 | 62 | 0.9 |
| | 71 | 1 22 | 1.4 |
| | 74 | 99 | 1.8 |
| | 96 | 43 | 1. 1 |
| | 130 | 65 | 0. 9 |
| | 134 | 74 | 0.6 |
| | 150 | 19 | 0.3 |
| | 163 | 156 | 1.9 |
| | 172 | 98 | 1, 0 |
| | 201 | 28 | 0.6 |
| | 206 | 57 | 0.3 |
| | 213 | 36 | 0. 2 |
| | 308 | 12 | 0. 3 |
| | 331 | 22 | 0.5 |
| | 366 | 224 | 3.2 |
| | 417 | 23 | C). 6 |
| | 486 | 49 | 0. 6 |
| | 495 | 99 | 0.7 |
| Totals: | 22 | 1466 | 19. & |

RUN 3: 477 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 13 | 38 | 0.7 |
| 53 | 5 | 0.4 |
| 58 | 68 | 0.5 |
| 42 | 52 | 0.8 |
| 80 | 117 | 1.7 |
| 98 | 56 | 0.8 |
| 126 | 14 | 0.3 |
| 148 | 46 | 0. E? |
| 18'7 | 20 | 0.7 |
| 206 | 113 | 1.6 |
| 247 | 87 | 0.7 |
| 271 | 313 | 3.3 |
| 274 | 24 | 0.2 |
| 298 | 28 | 0.7 |
| 313 | 54 | 0.4 |
| 348 | 42 | 0.6 |
| 439 | 45 | 0.6 |
| 444 | 94 | 1.7 |
| 445 | 64 | 0.8 |
| 448 | 52 | 1.9 |
| 469 | 61 | 0.5 |
| 469 | 125 | 0.9 |
| 486 | 127 | 1. El |
| Totals: 23 | 1645 | 22.7 |

RUN 4: 480 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 10 | 60 | 0.9 |
| 28 | 53 | 0.6 |
| 29 | 61 | 0.6 |
| 50 | 98 | 1.2 |
| 68 | 66 | 0.6 |
| 95 | 66 | 0.5 |
| 152 | 52 | 1.1 |
| 247 | 47 | 0.6 |
| 266 | 55 | 0.6 |
| 267 | 56 | 0.6 |
| 276 | 133 | 1.6 |
| 279 | 51 | 0.8 |
| 286 | 34 | 0.6 |
| 334 | 8 | 0.0 |
| 368 | 116 | 1.2 |
| 402 | 34 | 0. El |
| 403 | 8 | 0.2 |
| 428 | 66 | 0.9 |
| 484 | 73 | 1.2 |
| 495 | 39 | 1.0 |
| Totals: 20 | 1176 | 15.7 |

RUN 7: 493 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 26 | 55 | 1.8 |
| 61 | 67 | 0.8 |
| 132 | 23 | 0.5 |
| 218 | 78 | 1.2 |
| 272 | 55 | 0.5 |
| 305 | 5 | 0.4 |
| 487 | 32 | 0.3 |
| Totals: 7 | 315 | 5.4 |

RUN 9: 497 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 69 | 116 | i.9 |
| 354 | 5 | 0.2 |
| 488 | 42 | 0.6 |
| Totals: 3 | i 63 | 2.8 |

RUN 13: 494 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 51 | 166 | 2. 1 |
| 69 | 137 | 1.8 |
| 1 ?2 | 25 | 0. i |
| 361 | 96 | 1.4 |
| 377 | 71 | 1. i |
| 468 | 156 | i. 6 |
| Totals: 6 | 651 | 8.2 |

RUN 15: 452 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 3 | 33 | 0.1 |
| | 9 | 19 | 0.3 |
| | 10 | 99 | 1.1 |
| | 16 | 27 | 0.5 |
| | 17 | 58 | 0.9 |
| | 39 | 47 | 0.7 |
| | 47 | 30 | 0.4 |
| | 71 | 39 | 0.9 |
| | 72 | 59 | 0.3 |
| | 74 | 13 | 0.2 |
| | 81 | 4 | 0.1 |
| | 88 | 29 | 0.5 |
| | 111 | 37 | 0.5 |
| | 118 | 67 | 0.5 |
| | 124 | 32 | 0.9 |
| | 149 | 96 | 0.7 |
| | 170 | 34 | 0.7 |
| | 195 | 47 | 0.7 |
| | 210 | 49 | 0.4 |
| | 213 | 148 | 1.2 |
| | 214 | 65 | 0.7 |
| | 229 | 10 | 0.1 |
| | 249 | 20 | 0.5 |
| | 252 | 61 | 0.5 |
| | 258 | 12 | 0.3 |
| | 267 | 47 | 0.5 |
| | 276 | 59 | 0.3 |
| | 278 | 93 | 1.0 |
| | 281 | 15 | 0.5 |
| | 288 | 5 | 0.1 |
| | 296 | 4 | 0.2 |
| | 313 | 32 | 0.6 |
| | 330 | 15 | 0.8 |
| | 353 | 41 | 0.9 |
| | 361 | 15 | 0.6 |
| | 369 | 77 | 0.5 |
| | 372 | 28 | 0.2 |
| | 387 | 70 | 0.6 |
| | 397 | 91 | 0.7 |
| | 417 | 16 | 0.1 |
| | 427 | 53 | 0.4 |
| | 429 | 30 | 0.4 |
| | 436 | 99 | 1.4 |
| | 442 | 9 | 0.1 |
| | 469 | 15 | 0.6 |
| | 483 | 23 | 0.7 |
| | 484 | 11 | 0.1 |
| | 494 | 23 | 0.2 |
| Totals: | 48 | 2006 | 25.4 |

RUN 19: 497 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 137 | 67 | 0.9 |
| 325 | 4 | C). 4 |
| 454 | 5 | 0. 5 |
| Totals: 3 | 76 | 1. 8 |

RUN 20: 490 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 51 | 40 | 0. 7 |
| 148 | 9a | 1.2 |
| 235 | 51 | 0.9 |
| 360 | 52 | 0.9 |
| 361 | 145 | 1. 5 |
| 379 | 127 | 1.0 |
| 429 | 93 | 1. 1 |
| 443 | 57 | 0. 6 |
| 458 | 71 | 0.7 |
| 499 | 70 | 0. 9 |
| Totals: 10 | 804 | 9. 5 |

RUN 23: 484 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 55 | 94 | 0.9 |
| 86 | 71 | 0.8 |
| 95 | 88 | 0.7 |
| 123 | 91 | 0.7 |
| 1 24 | 44 | 0.9 |
| 157 | 37 | 0.4 |
| 17!5 | 9 | 0.3 |
| 205 | 113 | 1.6 |
| 211 | 52 | Q. 3 |
| 219 | 39 | 0.6 |
| 348 | 56 | 0. 6 |
| 354 | 80 | 0. 9 |
| 371 | 99 | 0. ? |
| 387 | 146 | 1.2 |
| 422 | 8 | 0.6 |
| 461 | 73 | 1. 3 |
| Totals: 16 | 1100 | 12. 7 |

Table B. 10 Numberof surfacings in oil and time in oiled water for individual gray whale points for each spill scenario at Beaufort site 5 (summer spills) resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 34 gray whales.

RUN 6: 488 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 2 | 45 | 1.2 |
| | 21 | 183 | 4.5 |
| | 101 | 127 | 3.1 |
| | 108 | 138 | 4.5 |
| | 123 | 99 | 3.0 |
| | 153 | 327 | 8.3 |
| | 224 | 34 | 0.9 |
| | 243 | 74 | 2.5 |
| | 24& | 67 | 1.9 |
| | 277 | 163 | 3.8 |
| | 376 | 117 | 3.0 |
| | 436 | 138 | 3.7 |
| Totals: | 12 | 1514 | 40.2 |

RUN 12: 4'95 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 9 | 7 | 0.3 |
| | 75 | 73 | 1.9 |
| | 231 | 45 | 1.1 |
| | 254 | 43 | 1.3 |
| | 283 | 14 | 0.4 |
| Totals: | 5 | 182 | 5.0 |

RUN 14: 4%5 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 79 | 148 | 3.9 |
| 123 | 84 | 2.4 |
| 170 | 81 | 2.3 |
| 349 | 86 | 2.2 |
| Totals: 4 | 399 | 10.9 |

RUN 16: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 67 | 32 | 0.7 |
| 109 | 129 | 3.5 |
| Totals: 2 | 161 | 4.2 |

RUN 24: 497 points from a total of 500 points did not hit ail.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 161 | 155 | 4.1 |
| 397 | 6 | 0.2 |
| 401 | 152 | 3.7 |
| Totals: 3 | 313 | 0.0 |

Table C. 1 Number of surfacings in oil and time in oiled water for individual bowhead whale points for each spill scenario at Chukchi site 1 (spring spills) resulting in whale-oil encounters. Valves are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 7. 6 bowhead whales.

RUN 2: 494 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 183 | 328 | 3.5 |
| | 228 | 78 | 0.8 |
| | 299 | 336 | 3.3 |
| | 428 | 121 | 1.2 |
| | 460 | 221 | 2.4 |
| | 463 | 635 | 9.0 |
| Totals: | 6 | 1719 | 20.2 |

RUN 3: 490 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 186 | 39 | 0.8 |
| | 208 | 15 | 0.3 |
| | 231 | 58 | u. 7 |
| | 334 | 27 | 0.7 |
| | 363 | 5 | 0.1 |
| | 37s | 62 | 0. '7 |
| | 453 | 56 | 0.8 |
| | 466 | 62 | 1.0 |
| | 467 | 118 | 2.1 |
| | 478 | 59 | 1.1 |
| Totals: | 10 | 501 | 8.5 |

RUN 5: 498 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 206 | 1 | 0.1 |
| | 299 | 168 | 2.5 |
| Totals: | 2 | 189 | 2.6 |

RUN 0: 497 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 302 | 151 | 1.3 |
| 308 | 53 | C).5 |
| 332 | 147 | 1.2 |
| Totals: 3 | 351 | 3.0 |

RUN 11: 4?? points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 424 | 65 | 0.8 |
| Totals: 1 | 65 | 0.8 |

RUN 14: 490 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 178 | 11 | 0.7 |
| 197 | 13 | 0.1 |
| 221 | 94 | 0.7 |
| 259 | 59 | 1.2 |
| 263 | 53 | 1.8 |
| 271 | 81 | #.6 |
| 295 | 36 | C).9 |
| 303 | 207 | 2.3 |
| 325 | 82 | 0.8 |
| 332 | 19 | 0.8 |
| Totals: 10 | 655 | 9.9 |

RUN 15: 482 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 191 | 42 | 1.0 |
| 224 | 116 | 2.2 |
| 271 | 17& | 2.7 |
| 309 | 127 | 2. 1 |
| 350 | 33 | 0. 6 |
| 353 | 30 | U. 2 |
| 370 | 4 | Q. 6 |
| 400 | 134 | 2.5 |
| 427 | 26 | 0. 2 |
| 433 | 61 | C?. 5 |
| 438 | 40 | 0. 4 |
| 464 | 95 | 1. i |
| 467 | 1 C0 | C?. 7 |
| 468 | 119 | 1.4 |
| 470 | 18 | 0. 3 |
| 475 | 251 | 3.8 |
| 490 | 47 | 0. 4 |
| 49s | 4 | Q. 3 |
| 18 | 1422 | 21.2 |

RUN 19: 492 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 185 | 52 | 0. 6 |
| | 201 | 31 | 0. 3 |
| | 222 | 133 | 1. 9 |
| | 269 | 47 | 0. 6 |
| | 275 | 1 63 | 2. 0 |
| | 300 | 37 | 0. 6 |
| | 304 | 99 | 1.2 |
| | 315 | 45 | 0.4 |
| Totals: | 8 | 607 | 7. El |

Table C.2 Number of surfacings in oil and time in oiled water for individual bowhead whale points for each spill scenario at Chukchi site 1 (summer spills) resulting in whale-ail encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale paints: each whale point represents 7.6 bowhead whales.

RUN 3: 490 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 62 | 114 | u.9 |
| | 135 | 45 | 0.7 |
| | 241 | 62 | 0.7 |
| | 253 | 68 | 1.0 |
| | 366 | 67 | 0.7 |
| | 378 | 26 | 0.2 |
| | 406 | 113 | 1.3 |
| | 426 | 98 | 1.3 |
| | 467 | 12 | 0.4 |
| | 497 | 44 | 0.5 |
| Totals: | 10 | 649 | 7.7 |

RUN 11: 493 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 70 | 53 | 0.5 |
| 117 | 1&o | i.9 |
| 174 | 1 34 | 2.0 |
| 213 | 208 | 2.8 |
| 245 | 141 | 1.3 |
| 261 | 56 | 1.0 |
| 400 | 190 | 1.7 |
| 7 | 942 | 11.2 |

RUN 14: 474 points from a total of 500 points did not hit oil

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 19 | 39 | 0.9 |
| 43 | 98 | 0.9 |
| 48 | 269 | 4.3 |
| 54 | 40 | 0.8 |
| 59 | 104 | 1.3 |
| 60 | 32 | 0.6 |
| 69 | 43 | 0.4 |
| 74 | 67 | 1.4 |
| 84 | 230 | 1.9 |
| 85 | 113 | 1.0 |
| 112 | 23 | 0.6 |
| 114 | 186 | 2.2 |
| 150 | 36 | 0.7 |
| 186 | 73 | 1.4 |
| 230 | 139 | 1.0 |
| 260 | 63 | 1.3 |
| 278 | 37 | 0.7 |
| 283 | 43 | 0.7 |
| 308 | 20 | 0.3 |
| 338 | 64 | 1.1 |
| 388 | 95 | 0.9 |
| 399 | 144 | 1.7 |
| 436 | 110 | 1.2 |
| 463 | 4 | 0.0 |
| 488 | 19 | 0.2 |
| 494 | 109 | 1.0 |
| Totals: 26 | 2200 | 28.5 |

RUN 15: 490 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 17 | 10 | 0.5 |
| 68 | 74 | 0.7 |
| 86 | 102 | 1.9 |
| 193 | 65 | 0.5 |
| 196 | 32 | 0.5 |
| 284 | 22 | 0.2 |
| 364 | 125 | 1.4 |
| 413 | 135 | 1.9 |
| 482 | 144 | 2.2 |
| 493 | 58 | 1.0 |
| Totals: 10 | 7457 | 10.8 |

RUN 19: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 5 | 258 | 2. El |
| 58 | 65 | 1.0 |
| 1 06 | 7 | 0. 9 |
| 121 | 170 | 1.8 |
| 161 | 12 | 0. 5 |
| 170 | 78 | 1. 1 |
| 228 | 48 | 0. 5 |
| 242 | 47 | 0. 4 |
| 313 | 32 | 0.7 |
| 3A 1 | 61 | 1. 3 |
| 386 | 20 | 0. 6 |
| 491 | 69 | 1. 2 |
| Totals: 12 | 867 | 12. 8 |

RUN 20: 492 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 12 | 76 | 0. 9 |
| 1'53 | 4 | 0. 8 |
| 211 | 63 | i). 7 |
| 275 | 27 | 0. 7 |
| 307 | 64 | 0. 7 |
| 378 | 69 | u. 8 |
| 451 | 87 | 1. 0 |
| 475 | 80 | 1. 1 |
| Totals: 8 | 470 | 6. 7 |

RUN 21: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 42 | 40 | 0. 9 |
| 115 | 10 | 0. 8 |
| Totals: 2 | 50 | 1. 7 |

RUN 25: 494 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 2 | 21 | 0.4 |
| | 169 | 157 | i. 7 |
| | 288 | 49 | 0.6 |
| | 307 | 43 | 1.4 |
| | 354 | 90 | 0.9 |
| | 488 | 52 | 1.4 |
| Totals: | 6 | 412 | 6.4 |

Table C.3 Number of surfacings in oil and time in oiled water for individual gray whale points for each spill scenario at Chukchi site 1 (summer spills) resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 34 gray whales.

RUN 1: 4S3 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 25 | 109 | 3.1 |
| | 32 | 35 | 1.1 |
| | 43 | 37 | 1.1 |
| | 72 | 24 | 0.6 |
| | 77 | 64 | 1.8 |
| | 83 | 139 | 3.1 |
| | 92 | 11 | 0.3 |
| | 131 | 29 | 0.7 |
| | 153 | 1 13 | 2.9 |
| | 1 152 | 12 | 0.3 |
| | 185 | 73 | 2.1 |
| | 204 | 21 | 0.9 |
| | 217 | 32 | U.8 |
| | 2S3 | 51 | 1.3 |
| | 284 | 33 | 1.2 |
| | 292 | 20 | 0.6 |
| | 395 | 3 | 0.2 |
| Totals: | 17 | 806 | 22.3 |

RUN 2: 490 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 21 | 54 | 1.3 |
| | 43 | 93 | 2.3 |
| | 47 | 86 | 2.3 |
| | 84 | 241 | 6.5 |
| | 97 | 78 | 2.3 |
| | 153 | 50 | 2.0 |
| | 154 | 17 | 0.5 |
| | 255 | 97 | 2.3 |
| | 256 | 20 | 0.5 |
| | 402 | 1 | 0.1 |
| Totals: | 10 | 737 | 20.1 |

RUN 6: 494 points from a tat-al of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 17 | 52 | 1.1 |
| 33 | 31 | 0.9 |
| 82 | 216 | 5.6 |
| 136 | 19 | 0.9 |
| 162 | 65 | 2.1 |
| i 70 | 40 | 0.8 |
| Totals: & | 423 | 11.4 |

RUN 9: 487 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 32 | 56 | 1.5 |
| 47 | 141 | 3.3 |
| 72 | 70 | 1.4 |
| 108 | 151 | 3.4 |
| 131 | 15 | 0.5 |
| 138 | 7 | 0.2 |
| 186 | 36 | 1.5 |
| 188 | 57 | 1.1 |
| 200 | 87 | 2.5 |
| 237 | 188 | 4.9 |
| 248 | 51 | 1.5 |
| 263 | 164 | 4.0 |
| 401 | 16 | 0.5 |
| Totals: 13 | 1039 | 26.3 |

RUN 10: 470 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in ail (hrs) |
|---|---|---|
| 25 | 60 | 1.2 |
| 32 | 49 | 1.3 |
| 33 | 20 | 0.6 |
| 34 | 79 | 2.2 |
| 82 | 183 | 4.4 |
| 85 | 313 | 8.4 |
| 108 | 21 | 0.6 |
| 123 | 185 | 5.4 |
| 132 | 162 | 4.4 |
| 134 | 60 | 1.6 |
| 137 | 133 | 3.6 |
| 153 | 84 | 2.1 |
| 105 | 29 | 0.7 |
| 200 | 517 | 13.3 |
| 212 | 306 | 8.3 |
| 222 | 21 | 0.4 |
| 246 | 21 | 0.6 |
| 251 | 19 | 0.6 |
| 263 | 112 | 3.1 |
| 265 | 197 | 5.1 |
| 300 | 136 | 3.4 |
| 301 | 50 | 1.2 |
| 343 | 97 | 2.4 |
| 365 | 107 | 2.7 |
| 372 | 138 | 3.4 |
| 376 | 403 | 10.9 |
| 381 | 141 | 3.9 |
| 382 | 51 | 1.3 |
| 400 | 1&2 | 4.2 |
| 423 | 55 | 1.7 |
| 30 | 3911 | 103.0 |

RUN 13: 495 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 73 | 42 | 1..2 |
| | 132 | 216 | 5.7 |
| | 134 | 238 | 6.2 |
| | 245 | 36 | 1.1 |
| | 436 | 21 | 0.6 |
| Totals: | 5 | 573 | 15.0 |

RUN 18: 499 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 83 | 80 | 2.1 |
| Totals: 1 | 80 | 2.i |

RUN 21: 4?2 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 35 | 18 | 0.6 |
| 92 | 56 | 1.5 |
| 110 | 38 | 0.8 |
| 204 | 63 | 1.7 |
| 208 | 174 | 4.4 |
| 263 | 10 | 0.3 |
| 277 | 67 | 2.0 |
| 313 | 14e | 3.4 |
| Totals: 8 | 574 | 14.7 |

Table C.4 Number of surfacings in oil and time in oiled water for individual bowhead whale points for each spill scenario at Chukchi site 2 resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 7. 6 bowhead whales.

RUN 2: 499 points from a total of 500 points did not hit oil.

| | Whale pt II) # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 1 08 | 28 | 0. 7 |
| Totals: | 1 | 28 | 0. 7 |

RUN 3: 482 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 6 | 64 | 0. 9 |
| | 12 | 59 | 0. 9 |
| | 48 | 79 | 0. 9 |
| | 112 | 92 | 1. 6 |
| | 119 | 58 | i. 1 |
| | 120 | 112 | 1. 2 |
| | 124 | 15 | 0. 1 |
| | 160 | 41 | c). 9 |
| | 173 | 138 | 1. 1 |
| | 212 | 80 | 1. 6 |
| | 235' | 37 | 0. 5 |
| | 299 | 2 | 0. 2 |
| | 305 | 176 | 2. 4 |
| | 332 | 42 | 0. 5 |
| | 341 | 70 | 0. 8 |
| | 370 | 28 | 0. 1 |
| | 408 | 167 | 1. 8 |
| | 431 | 58 | 0. 7 |
| Totals: | 18 | 1318 | 17. 3 |

RUN 11: 485 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 4'7 | 86 | 0.7 |
| 73 | 173 | 1.8 |
| 131 | 249 | 2.7 |
| 151 | 34 | 0.7 |
| 154 | 17 | 0.6 |
| 159 | 62 | 0.6 |
| 165 | 156 | 2.1 |
| 169 | 38 | 0.4 |
| 194 | 59 | 0.6 |
| 243 | 143 | 1.6 |
| 313 | 33 | 0.5 |
| 324 | 87 | 1.4 |
| 345 | 28 | 0.1 |
| 443 | 118 | 1.5 |
| 496 | 140 | 2.0 |
| Totals: 15 | 1423 | 17.3 |

RUN 13: 499 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil(hrs) |
|---|---|---|
| 414 | 89 | 1..3 |
| Totals: i | 89 | 1.[illegible] |

RUN 16: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 410 | 47 | 0.5 |
| 466 | 20 | 0.3 |
| Totals: 2 | 67 | 0.8 |

RUN 22: 499 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 476 | 41 | 0.8 |
| Totals: 1 | 41 | G.8 |

Table C.5 Plumber of surfacings in oil and time in oiled water for individual bowhead whale points for each spill scenario at Chukchi site 3 (spring spills) resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 7.6 bowhead whales.

RUN 1: 492 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 172 | 2a | 0.7 |
| | 17s | 202 | 2.7 |
| | 235 | 57 | 1.0 |
| | 273 | 120 | 1.0 |
| | 303 | 68 | 1.8 |
| | 308 | 56 | 0.7 |
| | 329 | 114 | 1.5 |
| | 332 | 42 | 0.6 |
| Totals: | 8 | 687 | 10.0 |

RUN 2: 4?? points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 306 | 161 | 3.1 |
| Totals: | 1 | 161 | 3.1 |

RUN 4: 490 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 210 | 119 | 1.5 |
| | 315 | 35 | 0.2 |
| | 358 | 91 | 0.8 |
| | 389 | 4 | 0.0 |
| | 421 | 46 | 0.5 |
| | 434 | 67 | 0.9 |
| | 445 | 165 | 2.3 |
| | 488 | 12 | 0.1 |
| | 489 | 10? | 1.7 |
| | 491 | 278 | 3.6 |
| Totals: | 10 | 5'26 | 11.6 |

RUN 8: 480 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 171 | 101 | 1.0 |
| 190 | 239 | 3.2 |
| 191 | 85 | 1.1 |
| 200 | 90 | 0.9 |
| 202 | 67 | 0.5 |
| 214 | 113 | 1.4 |
| 222 | 60 | 0.8 |
| 225 | 37 | 0.6 |
| 230 | 471 | 4.7 |
| 256 | 94 | 0.El |
| 262 | 18 | 0.4 |
| 283 | 12 | 0.3 |
| 323 | 34 | 1.0 |
| 351 | 37 | 1.0 |
| 386 | 45 | 0.5 |
| 425 | 119 | 1.3 |
| 426 | 58 | 0.7 |
| 4'37 | 62 | 0.7 |
| 463 | 101 | 1.2 |
| 465 | 88 | 1.3 |
| Totals: 20 | 1931 | 23.4 |

RUN 10: 493 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 173 | 6 | G.4 |
| 180 | 106 | 1.3 |
| 197 | 91 | 0.? |
| 214 | 73 | 1.4 |
| 220 | 36 | 1.0 |
| 259 | 104 | 1.5 |
| 290 | 31 | 0.6 |
| 7 | 447 | 7.1 |

RUN 15: 444 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 161 | 11 | 0.4 |
| 175 | 52 | 1.4 |
| 177 | 54 | 0.9 |
| 178 | 42 | 1.0 |
| 187 | 73 | 0.9 |
| 208 | 79 | 0.8 |
| 209 | 127 | 1.6 |
| 235 | 97 | 0. 8 |
| 250 | 76 | 0.9 |
| 251 | 75 | 1.0 |
| 252 | 42 | 1.6 |
| 266 | 191 | 3.8 |
| 279 | 70 | 0. 6 |
| 280 | 28 | 0. 1 |
| 287 | 1=2 | 1. 5 |
| 288 | 74 | 1.3 |
| 296 | 63 | 1.0 |
| 302 | 154 | 2.0 |
| 312 | 357 | 4. 5 |
| 331 | 74 | 1. 5 |
| 335 | 177 | 2.2 |
| 339 | L 89 | 2. & |
| 356 | 80 | 1. 1 |
| 358 | 26 | 0.4 |
| 359 | 98 | 1. 8 |
| 363 | 64 | 1.7 |
| 365 | 1 84 | 2. 1 |
| 367 | 69 | 2. 6 |
| 368 | 51 | 1. 5 |
| 375 | 109 | 1. 4 |
| 376 | 70 | 1.7 |
| 377 | 18 | 0. 1 |
| 380 | 98 | 1.3 |
| 381 | 133 | 1.6 |
| 386 | 34 | 0. 8 |
| 387 | 129 | 1.3 |
| 390 | 102 | 1.3 |
| 391 | 79 | 1. 1 |
| 392 | 82 | 1.6 |
| 396 | 142 | 1.5 |
| 397 | 241 | 4.4 |
| 398 | 156 | 1.7 |
| 40 1 | 112 | 0. 8 |
| 40& | 66 | 1. 5 |
| 407 | 91 | 0.8 |
| 439 | 144 | 2.2 |
| 446 | 207 | 3. 1 |
| 451 | 110 | 1. 1 |
| 454 | 60 | 1. 1 |
| 4s6 | 48 | 0. 8 |
| 458 | 109 | 1.2 |
| 462 | 82 | 1.3 |
| 488 | 332 | 4.3 |
| 493 | 97 | 2.0 |
| 497 | 68 | 1. 1 |
| 498 | 136 | 2. 1 |
| Totals: 56 | 5934 | 87.0 |

RUN 17: 480 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 172 | 102 | 1.1 |
| 179 | 86 | 1.1 |
| 183 | 98 | 1.1 |
| 194 | 131 | 1.3 |
| 195 | 28 | 1.0 |
| 197 | 73 | 1.8 |
| 204 | 335 | 4.9 |
| 224 | 104 | 1.0 |
| 241 | 72 | 1.2 |
| 242 | 97 | 1.2 |
| 256 | 183 | 2.6 |
| 259 | 102 | 0.9 |
| 273 | 100 | 0.9 |
| 275 | 159 | 2.5 |
| 280 | 272 | 4.0 |
| 283 | 134 | 1.4 |
| 285 | 177 | 3.7 |
| 294 | 29 | 0.6 |
| 298 | 310 | 6.1 |
| 302 | 62 | 1.5 |
| Totals: 20 | 2654 | 39.9 |

RUN 21: 486 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 170 | 152 | 1.5 |
| 192 | 295 | 3.1 |
| 216 | 24 | 0.5 |
| 230 | 119 | 1.5 |
| 232 | 35 | 0.6 |
| 233 | 156 | 2.2 |
| 248 | 170 | 2.3 |
| 264 | 566 | 8.1 |
| 270 | 83 | 1.3 |
| 276 | 209 | 2.a |
| 287 | 53 | 1.8 |
| 291 | 116 | 1.4 |
| 299 | 194 | 2.1 |
| 320 | 21 | 0.2 |
| Totals: 14 | 2193 | 29.5 |

RUN 23: 469 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 14 | 55 | 0.7 |
| 58 | 41 | 0.5 |
| 61 | 17s | 2.3 |
| 168 | 44 | 1.0 |
| 206 | 24 | 0.7 |
| 210 | 63 | 0.8 |
| 251 | 150 | 1.8 |
| 254 | 161 | 1.4 |
| 255 | 1 47 | 1.1 |
| 280 | 70 | 1.0 |
| 286 | 184 | 1.3 |
| 310 | 123 | 2.1 |
| 328 | 53 | 1.0 |
| 342 | 90 | 0.9 |
| 344 | 126 | 1.7 |
| 351 | 86 | 0.7 |
| 367 | 340 | 7.0 |
| 374 | 115 | 1.7 |
| 376 | 191 | 2.9 |
| 388 | 320 | 4.9 |
| 391 | 116 | 1.4 |
| 393 | 287 | 2.7 |
| 408 | 107 | 1.4 |
| 414 | 47 | 0.6 |
| 416 | 86 | 1.3 |
| 423 | 70 | L?.9 |
| 425 | 114 | 1.6 |
| 428 | 94 | 1.5 |
| 431 | 42 | 1.0 |
| 447 | 44 | 0.5 |
| 458 | 1 #7 | 1.7 |
| Totals: 31 | 3672 | 50.1 |

RUN 24: 474 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 190 | 121 | 1.0 |
| 212 | 100 | 1.2 |
| 213 | 132 | 1.1 |
| 215 | 206 | 2.2 |
| 216 | 134 | 1.4 |
| 234 | 20 | 0.5 |
| 248 | 49 | 1.1 |
| 253 | 84 | 1.0 |
| 276 | 279 | 3.5 |
| 277 | 109 | 1.3 |
| 291 | 140 | 2.2 |
| 307 | 116 | 1.1 |
| 311 | 130 | 1.7 |
| 315 | 82 | 1.0 |
| 321 | 38 | 0.7 |
| 336 | 55 | 1.4 |
| 351 | 203 | 2.1 |
| 374 | 58 | 0.8 |
| 375 | 118 | 1.4 |
| 389 | 61 | 0.8 |
| 3?2 | 20 | 0.5 |
| 460 | 10 | 0.5 |
| 463 | 122 | 1.8 |
| 473 | 122 | 1.9 |
| 477 | 108 | 1.6 |
| 491 | 98 | 0.9 |
| **Totals:** 26 | 2715 | 34'.7 |

Table C.6 Number of surfacings in oil and time in oiled water for individual gray whale points for each spill scenario at Chukchi site 3 (spring spills) resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 34 gray whales.

RUN 5: 499 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 126 | 35 | 0.7 |
| Totals: | 1 | 35 | 0.7 |

RUN 8: 484 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 14 | 137 | 3.6 |
| | 15 | 38 | 1.3 |
| | 17 | 69 | 1.5 |
| | 18 | 23 | C?.7 |
| | 21 | 34 | 1.2 |
| | 24 | 65 | 1.7 |
| | 2s | 108 | 2.7 |
| | 27 | 18 | 0.3 |
| | 36 | 441 | 10.9 |
| | 44 | 104 | 3.2 |
| | 111 | 83 | 2.6 |
| | 125 | 45 | 1.4 |
| | 166 | 29 | 0.8 |
| | 194 | 16 | 0.6 |
| | 198 | 20 | 0.5 |
| | 260 | 19 | 0.6 |
| Totals: | 16 | 1249 | 33.8 |

Table C.7 Number of surfacings in oil and time in oiled water for individual gray whale points for each spill scenario at Chukchi site 3 (summer spills) resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale Point represents 34 gray 'hales"

RUN 1: 491 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 9 | 26 | 0.7 |
| 32 | 17 | 0.4 |
| 46 | 118 | 3.1 |
| 84 | 5 | 0.2 |
| 113 | 27 | 0.6 |
| 133 | 19 | 0.7 |
| 134 | 38 | 1.0 |
| 224 | 23 | 0.13 |
| 356 | 19 | 0.7 |
| Totals: 9 | 292 | 8.2 |

RUN 2: 499 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 51 | 33 | 0.8 |
| Totals: 1 | 33 | 0.8 |

RUN 7: 494 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 12 | 140 | 3.9 |
| 24 | 27 | 0.8 |
| 62 | 26 | 0.7 |
| 250 | 10 | 0.2 |
| 314 | 73 | 1.6 |
| 412 | 77 | 2.1 |
| Totals: 6 | 353 | 9.3 |

RUN 9: 465 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 8 | 82 | 2.1 |
| 11 | 59 | 1.6 |
| 28 | 172 | 4.7 |
| 32 | 170 | 4.0 |
| 35 | 63 | 2.0 |
| 41 | 105 | 2.5 |
| 54 | 113 | 2.6 |
| 58 | 35 | 0.9 |
| 69 | 73 | 2.3 |
| 90 | 33 | 1.0 |
| ?3 | 161 | 4.9 |
| 121 | 86 | 2.4 |
| 126 | 73 | 1.9 |
| 131 | 45 | 1.1 |
| 133 | 31 | 0.6 |
| 142 | 418 | 10.S |
| 145 | 15 | 0.2 |
| 158 | 65 | 2.0 |
| 159 | 66 | 1.6 |
| 179 | 26 | 0.6 |
| 187 | 30 | 0.9 |
| 203 | 19 | 0.4 |
| 206 | 81 | 2.6 |
| 208 | 51 | 1.1 |
| 220 | 162 | 5.0 |
| 232 | 33 | 0.6 |
| 262 | 167 | 4.3 |
| 270 | 23 | 0.5 |
| 276 | 43 | 0.3 |
| 297 | 63 | 1.3 |
| 362 | 15 | 0.2 |
| 365 | 195 | 5.0 |
| 423 | 33 | 0.6 |
| 431 | 133 | 4.0 |
| 439 | 24 | 0.8 |
| Totals: 35 | 2963 | 77.9 |

RUN 10: 495 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 153 | 29 | 0.9 |
| 216 | 57 | 1.7 |
| 378 | 21 | 0.5 |
| 442 | 16 | 0.4 |
| 462 | 176 | 5.0 |
| Totals: 5 | 299 | 8.5 |

RUN 19: 499 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 268 | 13 | 0.3 |
| Totals: 1 | 13 | 0.3 |

RUN 21: 475 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Tine in oil (hrs) |
|---|---|---|
| 10 | 136 | 3.6 |
| 28 | 101 | 2.5 |
| 39 | 71 | 2.1 |
| 41 | 153 | 4.0 |
| 42 | 80 | 2.5 |
| 51 | 62 | 1.8 |
| 60 | 120 | 3.0 |
| 79 | 282 | 6.3 |
| 86 | 39 | 1.1 |
| 87 | 96 | 2.4 |
| 111 | 40 | 1.1 |
| 124 | 6 | 0.1 |
| 128 | 200 | 5.3 |
| 131 | 156 | 3.9 |
| 136 | 67 | 1.6 |
| 147 | 55 | 1.6 |
| 176 | 19 | 0.6 |
| 179 | 55 | 1.6 |
| 194 | 163 | 4.3 |
| 205 | 74 | 2.0 |
| 248 | 27 | 0.7 |
| 250 | 22 | 0.6 |
| 261 | 52 | 1.6 |
| 262 | 205 | 5.3 |
| 273 | 87 | 2.4 |
| Totals: 25 | 2368 | 62.5 |

RUN 25: 484 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 4 | 121 | 3.3 |
| 5 | 37 | 0.9 |
| 23 | 11 | 0.3 |
| 54 | 2 | 0.1 |
| 81 | 71 | 1.8 |
| 102 | 27 | 0.5 |
| 124 | 55 | 1.5 |
| 137 | 22 | 0.8 |
| 141 | 21 | 0.5 |
| 152 | 22 | 0.6 |
| 198 | 79 | 1.7 |
| 232 | 39 | 1.1 |
| 252 | 31 | 1.2 |
| 26s | 8 | 0.2 |
| 275 | 7 | 0.1 |
| 281 | 17 | 0.3 |
| Totals: 16 | 570 | 14.9 |

Table C.8 Number of surfacings in oil and time in oiled water for individual bowhead whale points for each spill scenario at Chukchi site 4 resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 7.6 bowhead whales.

RUN 4: 497 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 113 | 99 | 1.0 |
| 229 | 197 | 2.9 |
| 339 | 91 | 1.1 |
| Totals: 3 | 387 | 5.0 |

RUN 11: 497 points from a total of 500 points did not hit oil.

| Whale pt ID # | #? of hits | Time in oil (hrs) |
|---|---|---|
| '43 | 198 | 2.7 |
| 233 | 55 | 1.1 |
| 351 | 167 | 3.5 |
| Totals: 3 | 420 | 7.3 |

RUN 14: 496 points from a total of 500 points did not hit oil.

| Whale pt SD # | # of hits | Time in oil (hrs) |
|---|---|---|
| 12 | 6 | 0.6 |
| 132 | 2 | 0.o |
| 458 | 23 | 0.4 |
| 469 | 56 | u.9 |
| Totals: 4 | 87 | 1.? |

RUN 17: 490 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 60 | 12 | 0.9 |
| 78 | 20 | 0.3 |
| 110 | 35 | 0.8 |
| 131 | 1.20 | 1.5 |
| 186 | 19 | 0.3 |
| 211 | 134 | 2.7 |
| 280 | 150 | 1.3 |
| 372 | 87 | 0.8 |
| 443 | 16 | 0.15 |
| 493 | 12? | 1.7 |
| Totals: 10 | 722 | 10.9 |

Table C.9 Number of surfacings in oil and time in oiled water for individual gray whale points for each spill scenario at Chukchi site 4 resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 34 gray whales.

RUN 3: 496 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| ?7 | 185 | 4.7 |
| 211 | 41 | 1.3 |
| 212 | 58 | 2.2 |
| 402 | 62 | 1.5 |
| Totals: 4 | 346 | ?.7 |

RUN 4: 499 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 292 | 04 | 2.4 |
| Totals: 1 | 84 | 2.4 |

RUN 5: 496 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 9 | 244 | 7.0 |
| 137 | 57 | 1.4 |
| 174 | 58 | 1.5 |
| 283 | 59 | 1.9 |
| Totals: 4 | 418 | 11.8 |

RUN 6: 494 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 21 | 21 | 0.9 |
| 32 | 113 | 2.5 |
| 92 | 40 | 1.4 |
| 218 | 58 | 1.6 |
| 232 | 327 | a. 4 |
| 299 | 72 | 1.5 |
| Totals: 6 | 631 | 16.3 |

RUN S: 474 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 20 | 33 | 1.0 |
| 24 | 84 | 2.2 |
| 34 | 24 | 0.7 |
| 43 | 56 | 1.5 |
| 52 | 140 | 3.4 |
| 58 | 41 | 1.4 |
| 86 | 47 | 1.0 |
| ?5 | 44 | 1.4 |
| 101 | 24 | 0.5 |
| 106 | 373 | 8.3 |
| 151 | 60 | 1.6 |
| 163 | 19 | 0.6 |
| 205 | 194 | 4.7 |
| 206 | 103 | 2.8 |
| 214 | 90 | 2.0 |
| 222 | 339 | 9.2 |
| 224 | 25 | 0.6 |
| 241 | 393 | 9.3 |
| 244 | 88 | 2.2 |
| 2s2 | 267 | 6.8 |
| 268 | 95 | 2.7 |
| 346 | 40 | 1.3 |
| 352 | 272 | 7.6 |
| 366 | 87 | 2.2 |
| 419 | 52 | 1.6 |
| 436 | 169 | 4.6 |
| Totals: 26 | 3159 | 81.4 |

RUN 9: 495 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 17 | 21 | u. 5 |
| 97 | 109 | 3.3 |
| 298 | 59 | 1.4 |
| 308 | 150 | 3. 9 |
| 383 | 35 | 1. 0 |
| Totals: 5 | 374 | 10. 1 |

RUN 11: 499 points from a total of 500 points did not hit' oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 62 | 98 | 2.4 |
| Totals: 1 | 98 | 2.4 |

RUN 13: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 252 | 39 | 1. 0 |
| 328 | 84 | 2. 4 |
| Totals: 2 | 123 | 3.4 |

RUN 15: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 117 | 219 | 5.7 |
| 307 | 190 | 4.7 |
| Totals: 2 | 409 | 10. 4 |

RUN 16: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 31 | 54 | 1.5 |
| 121 | 1 66 | 4.5′ |
| Totals: 2 | 220 | 6.4 |

RUN 17: 496 paints from a total of ’500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 43 | 15 | 0. 5 |
| 162 | 44 | 1. 1 |
| 1 88 | 39 | 1. 1 |
| .255 | 60 | 1. 7 |
| Totals: 4 | 158 | 4.4 |

RUN 20: 47? points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 28 | 45 | 1.4 |
| 46 | 31 | 1. 0 |
| 64 | 85 | 1. 9 |
| 72 | 157 | 4.4 |
| 88 | 103 | 3. 1 |
| 99 | 101 | 2. 7 |
| 129 | 48 | 1. 1 |
| 137 | 37 | Y.. 1 |
| 161 | 145 | 3.2 |
| 180 | 1 | 0. 0 |
| 190 | 98 | 2. ? |
| 201 | 31 | 0.7 |
| 202 | 106 | 5.4 |
| 204 | 93 | 2.8 |
| 217 | E? | 2. 4 |
| 221 | 253 | 6. 1 |
| 260 | 127 | 3. 5 |
| 327 | 30 | 0. 9 |
| 375 | 74 | 2. 2 |
| 410 | 101 | 2.5 |
| 444 | 19 | 0.6 |
| Totals: 21 | 1854 | 49. 9 |

RUN 21: 494 points from a total of 500 points did not hit *oil.*

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 8 | 132 | 3.4 |
| 88 | 273 | 7.0 |
| 103 | 72 | 2.1 |
| 251 | 133 | 4.1 |
| 278 | 169 | 4.5 |
| 333 | 77 | 2.4 |
| **Totals:** 6 | 856 | 23.5 |

RUN 22: 49& points from a total of 500 points did not hit oil.

| Whale pt II) # | # of hits | Time inoil(hrs) |
|---|---|---|
| 158 | 21 | 0.5 |
| 230 | 39 | 0.7 |
| 263 | 397 | 9.9 |
| 380 | 69 | 2.0 |
| Totals: 4 | 526 | 13.1 |

RUN 23: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 278 | 143 | 3.2 |
| 280 | 174 | 4.6 |
| **Totals:** 2 | 317 | 7.8 |

RUN 24: 496 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 28 | 271 | 7.2 |
| 204 | 39 | 1.1 |
| 207 | 4 | 0.0 |
| 243 | 46 | 1.3 |
| Totals: 4 | 360 | 9.6 |

Table C. 10 Number of surfacings in oil and time in oiled water for individual gray whale points for each spill scenario at Chukchi site 5 (summer spills) resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 34 gray whales.

RUN 1: 460 points from a total of 500 points did not hit oil,

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 10 | 2'? | 1.0 |
| 13 | 46 | 1.3 |
| 19 | 54 | 1.8 |
| 22 | 2 | 0.0 |
| 2s | 50 | 1.2 |
| 33 | 45 | 1. 4 |
| 44 | 76 | 2. 0 |
| 59 | ?2 | 2. 3 |
| 80 | 11 | 0.2 |
| 8.2 | 4s | 1. 1 |
| 113 | 83 | 2. 0 |
| 114 | 55 | 1.3 |
| 118 | 293 | 8.4 |
| 124 | 150 | 4. 2 |
| 126 | 377 | 9. 6 |
| 127 | 34 | 1.0 |
| 160 | 45 | 1. 4 |
| 164 | 1. 22 | 3.0 |
| 199 | 110 | 3.3 |
| 20s | i co | 2. 4 |
| 212 | 30 | 0. 6 |
| 215 | 81 | 2. 3 |
| 221 | 224 | 3.5 |
| 229 | 30 | 0. 8 |
| 231 | 125 | 4. 2 |
| 234 | 46 | 1.2 |
| 2S7 | 328 | 8.7 |
| 263 | 1'20 | 3. 1 |
| 27S | 82 | 2.6 |
| 312 | 66 | 1.? |
| 3.20 | 42 | 0.9 |
| 322 | 56 | 1. 1 |
| 353 | 16s | 4. 1 |
| 363 | 70 | 1.9 |
| 366 | 139 | 4. 0 |
| 367 | 36 | 1.4 |
| 436 | 38 | 1.2 |
| 448 | 77 | 2.0 |
| 450 | 119 | 2.7 |
| 455 | 71 | 1.0 |
| Totals: 40 | 3764 | 100. 9 |

RUN 2: 496 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 119 | 284 | 7.5 |
| 232 | 206 | 5.6 |
| 237 | 202 | 4.7 |
| 245 | 13 | 0.4 |
| Totals: 4 | 705 | 10.2 |

RUN 3: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 416 | 14 | 0.2 |
| 438 | 40 | 0.7 |
| Totals: 2 | 54 | u.? |

RUN 4: 497 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 140 | 155 | 4.0 |
| 155 | 22 | C).7 |
| 208 | 30 | 0.7 |
| Totals: 3 | 207 | 5.4 |

RUN 6: 493 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 110 | 35 | C).8 |
| 181 | 37 | 1.1 |
| 219 | 71 | 1.8 |
| 269 | 141 | 4.0 |
| 281 | 28 | 0.6 |
| 390 | 9? | 2.3 |
| 439 | 1 | C).0 |
| Totals: 7 | 412 | 10.6 |

RUN 8: 494 points from a total of 300 points did not hit oil.

| | Whale pt ID # | # Of hits | Time in oil (hrs) |
|---|---|---|---|
| | 28 | 110 | 2.8 |
| | 46 | 146 | 4.0 |
| | 65 | 73 | 2.2 |
| | 112 | 109 | 2.8 |
| | 190 | 70 | 2.2 |
| | 204 | 15 | 0.5 |
| Totals: | 6 | 523 | 14.5 |

RUN 9: 487 points from a total of .500 points did not hit oil.

| | Whale pt ID # | # of hits | T: in oil (hrs) |
|---|---|---|---|
| | | 26 | 0.8 |
| | | 83 | 2.2 |
| | 115 | 33 | 0.8 |
| | 166 | 202 | 5.1 |
| | 171 | 79 | 1.6 |
| | 178 | 87 | 2.2 |
| | 180 | 12 | 0.2 |
| | 276 | 137 | 3.7 |
| | 2?6 | 40 | 1.1 |
| | 414 | 46 | 1.4 |
| | 420 | 16 | 0.5 |
| | 454 | ?8 | 2.6 |
| | 461 | 2? | 0.0 |
| Totals: | 13 | 888 | 23.0 |

RUN 10: 487 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 7 | 44 | 0.8 |
| | 30 | 201 | 5.2 |
| | 44 | 78 | 1.7 |
| | 76 | 295 | 8.4 |
| | 128 | 135 | 3.2 |
| | 140 | 38 | 1.0 |
| | 158 | 140 | 3.8 |
| | 232 | 69 | 1.6 |
| | 237 | 49 | 1.1 |
| | 239 | 55' | 1.8 |
| | 286 | 110 | 2.4 |
| | 359 | 63 | 1.7 |
| | 437 | 73 | 1.7 |
| Totals: | 13 | 1350 | 34.4 |

RUN 11: 470 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in Oil (hrs) |
|---|---|---|
| 7 | 35 | 0.7 |
| ? | 58 | 1.6 |
| 15 | 48 | 1.2 |
| 18 | 161 | 4.5 |
| 21 | 109 | 2.4 |
| 64 | 231 | 5.4 |
| 80 | 146 | 3.2 |
| 83 | 191 | 5.3 |
| 88 | 316 | 7.9 |
| 97 | 83 | 2.3 |
| 109 | 41 | C).8 |
| 121 | 79 | 2.1 |
| 162 | 369 | 9.2 |
| 163 | 153 | 3.7 |
| 1?2 | 4 | 0.1 |
| 204 | 76 | 2.3 |
| 230 | 44 | 1.0 |
| 254 | 295 | 0.0 |
| 268 | 161 | 4.0 |
| 27 0 | 144 | 3.8 |
| 286 | 19 | 0.5 |
| 320 | 12!3 | 3.5 |
| 335 | 161 | 4.0 |
| 348 | 172 | 4,6 |
| 358 | 18 | 0.6 |
| 365 | 383 | 10.6 |
| 382 | 490 | 13.0 |
| 420 | 94 | 2.8 |
| 458 | 20 | 0.6 |
| 465 | 64 | 1.7 |
| **Totals:** 30 | 4293 | 111.4 |

RUN 12: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 1 00 | 177 | 4.3 |
| 362 | 85 | 2.0 |
| **Totals:** 2 | 242 | 6.3 |

RUN 18: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 150 | 262 | 7.5 |
| 185 | 141 | 3.8 |
| Totals: 2 | 403 | 11.3 |

RUN 19: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 6 | 55 | 1.8 |
| 267 | 118 | 2.9 |
| Totals: 2 | 173 | 4.7 |

RUN 22: 494 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 13 | 42 | 1.7 |
| 88 | 184 | 4.7 |
| 133 | 10 | 0.5 |
| 165 | 43 | 1.2 |
| 181 | 95 | 2.2 |
| 203 | 41 | 0.9 |
| 6 | 415 | 11.2 |

RUN 23: 496 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 49 | 136 | 4.0 |
| 68 | 133 | 3.1 |
| 224 | 133 | 3.3 |
| 399 | 34 | 0.7 |
| Totals: 4 | 436 | 11.1 |

RUN 24: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in Oil (hrs) |
|---|---|---|
| 106 | 92 | 2.5 |
| 308 | 56 | 1.4 |
| **Totals:** 2 | 148 | 3. Y |

RUN 25: 497 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 119 | 10 | 0.3 |
| 13& | 92 | 2. 1 |
| 218 | 33 | 1.0 |
| **Totals:** 3 | 135 | 3.4 |

Table C. 11 Number of surfacings in oil and time in oiled water for individual bowhead whale points for each spill scenario at Chukchi site 5 (autumn spills) resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 7.6 bowhead whales.

RUN 8: 499 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 59 | 100 | 1.1 |
| Totals: 1 | 100 | 1.1 |

RUN 18: 496 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 55 | 231 | 2.9 |
| 59 | 23 | 0.2 |
| 414 | 53 | 0.9 |
| 473 | 77 | 1.0 |
| Totals: 4 | 384 | 5.0 |

RUN 23: 491 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 22 | 44 | 0.7 |
| 102 | 52 | 0.6 |
| 137 | 59 | 1.2 |
| 202 | 77 | 1.5 |
| 372 | 36 | 0.7 |
| 375 | 116 | 1.0 |
| 379 | 13 | 0.4 |
| 449 | 144 | 1.8 |
| 475 | 91 | 0.9 |
| Totals: 9 | 632 | 8.8 |

Table C. 12 Number of surfacings in oil and time in oiled water for individual gray whale points for each spill scenario at Chukchi site 5 {autumn spills) resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 34 gray whales.

RUN 4: 493 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 78 | 104 | 2.8 |
| 120 | 17 | 0. 5 |
| 1 80 | 228 | 6. 3 |
| 260 | 3s | 0.9 |
| 261 | 60 | 1. 6 |
| 327 | 183 | 4.5 |
| 341 | 59 | 1.4 |
| Totals: 7 | 706 | 18. 0 |

RUN 5: 499 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 254 | 129 | 3. 0 |
| Totals: 1 | 129 | 3. 0 |

RUN 8: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 106 | 1 08 | 2. 6 |
| 260 | 102 | 2. 5 |
| Totals: 2 | 210 | 5. 1 |

RUN 13: 497 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 205 | 46 | 1.0 |
| 301 | 47 | 1.4 |
| 425 | 31 | 1.1 |
| Totals: 3 | 124 | 3.5 |

RUN 17: 487 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 32 | 5 | 0.1 |
| 35 | 59 | 1.4 |
| 57 | 62 | 1.5 |
| 73 | 427 | 10.1 |
| 04 | 225 | 6.6 |
| 132 | 29 | 0.6 |
| 137 | 109 | 2.8 |
| 141 | 134 | 3.3 |
| 230 | 47 | 1.2 |
| 245 | 41 | 1.1 |
| 253 | 183 | 4.7 |
| 277 | 173 | 4.8 |
| 299 | 105 | 3.1 |
| Totals: 13 | 1599 | 41.3 |

RUN 18: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 33 | 61 | 1.7 |
| 123 | 31 | 0.9 |
| Totals: 2 | 92 | 2.6 |

RUN 21: 499 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 198 | 49 | 1.6 |
| Totals: 1 | 49 | 1.6 |

RUN 23: 496 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 76 | 151 | 3.6 |
| 153 | 125 | 3.0 |
| 242 | 98 | 2.6 |
| 317 | 63 | 1.5 |
| Totals: 4 | 437 | 10.7 |

**Table** D. 1 Number of surfacings in oil and time in oiled water for individual gray whale points for each spill seen:ario at St. George site 1 (spring spills) resulting in whale-oil encounters. Values are talculated at 10 days after the last oil release. Notethat results are presented for whale points: ●ach whale point represents 34 gray whales.

RUN 3: 443 points from a total of 500 points did not hit oil

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 84 | 31 | 1.3 |
| 86 | 123 | 2.9 |
| 92 | 44 | 1.2 |
| ?7 | 22 | 0.5 |
| 99 | 71 | 1.9 |
| 100 | 226 | S. 3 |
| 104 | 107 | 2.9 |
| 105 | 40 | 1.6 |
| 111 | 395 | 10.3 |
| 113 | 48 | 1.2 |
| 117 | 37 | 1.0 |
| 122 | 189 | 4.0 |
| 123 | 116 | 3.0 |
| 127 | 131 | 3.3 |
| 130 | 66 | 1.7 |
| 133 | 99 | 2.6 |
| 134 | 109 | 2.9 |
| 147 | 121 | 3.2 |
| 149 | 17s | 4.3 |
| 190 | 207 | 6.3 |
| 192 | 107 | 2. a |
| 160 | 171 | 4.2 |
| 161 | 116 | 3.0 |
| 162 | 182 | 5.3 |
| 1&4 | 203 | 5. 5 |
| 165 | 207 | S. 2 |
| 166 | 262 | 7.0 |
| 167 | 93 | 2.7 |
| 169 | 72 | 1.6 |
| 170 | 233 | 6. 0 |
| 172 | 161 | 4.3 |
| 173 | 143 | 3.4 |
| 174 | 82 | 2.4 |
| 173 | 138 | 4.2 |
| 177 | 342 | B. 8 |
| 17B | 163 | 4.6 |
| 17'7 | 81 | 2.3 |
| 181 | 276 | 6.5 |
| 182 | 120 | 3.4 |
| 184 | 137 | 4.3 |
| 185 | 254 | &. 4 |
| 187 | 92 | 2.3 |
| 188 | 199 | 3.4 |
| 1 89 | 102 | 2.7 |
| 190 | 88 | 1.7 |
| 191 | 68 | 2.0 |
| 199 | 126 | 4.0 |
| 19& | 94 | 2.3 |
| 198 | 104 | 2. a |
| 199 | 2 | 0.1 |
| 200 | 146 | 3. 6 |
| 204 | 166 | 4.9 |
| 22a | 107 | 2.7 |
| 237 | 86 | 2.2 |
| 239 | 14 | 0.4 |
| 249 | 95 | 2. 8 |
| 291 | 31 | 0.8 |
| Totals: 57 | 7406 | 194.6 |

RUN 4: 438 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 58 | 112 | 3.0 |
| 63 | 73 | 2.2 |
| 65 | 68 | 1.7 |
| 69 | 141 | 3.2 |
| 7? | 157 | 4.3 |
| 81 | 125 | 3.4 |
| 83 | 226 | 6.1 |
| 85 | 304 | 7.? |
| 86 | 241 | 6.2 |
| 90 | 24 | 0.7 |
| 91 | 41 | 1.5 |
| ?3 | 78 | 2.4 |
| ?3 | 11s | 3.3 |
| 97 | 72 | 1.? |
| 101 | 6 | 0.1 |
| 102 | 33 | 0.9 |
| 103 | 169 | 3.9 |
| 10s | 33 | 1.1 |
| 111 | 42 | 1.2 |
| 113 | 78 | 2.3 |
| 118 | 221 | S.3 |
| 120 | 35 | 1.0 |
| 12s | 114 | 2.9 |
| 130 | 89 | 2.8 |
| 134 | 234 | 6.9 |
| 13s | 189 | 4.7 |
| 136 | 194 | 4.1 |
| 137 | 2B4 | 7.3 |
| 138 | 28 | 0.9 |
| 141 | 37 | 1.1 |
| 144 | 196 | 5.1 |
| 148 | 196 | 5.1 |
| 14? | 289 | 7.7 |
| 150 | 51 | 1.3 |
| 153 | 42 | 1.3 |
| 159 | 167 | 5.0 |
| 159 | 180 | 4.0 |
| 160 | 85 | 2.3 |
| 166 | 272 | 6.B |
| 169 | 131 | 3.8 |
| 170 | 335 | El.6 |
| 171 | 73 | 1.8 |
| 173 | 129 | 3.6 |
| 174 | 313 | 8.7 |
| 180 | 198 | 3.0 |
| 183 | 1GO | 2.4 |
| 187 | 3? | 1.0 |
| 192 | 250 | 6.4 |
| 193 | 184 | 4.4 |
| 195 | 343 | 9.6 |
| 196 | 271 | 7.2 |
| 1?7 | 245 | 6.6 |
| 200 | 84 | 2.1 |
| 202 | 132 | 3.8 |
| 205 | 108 | 3.0 |
| 208 | 12s | 2.9 |
| 210 | 128 | 2.6 |
| 211 | 143 | 4.1 |
| 213 | 205 | S.1 |
| 214 | 131 | 3.6 |
| 219 | 190 | 4.? |
| 223 | 89 | 2.6 |
| Totals: 62 | 8987 | 237.0 |

RUN 6: 499 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 298 | 159 | 4.2 |
| **Totals:** 1 | 15-9 | 4.2 |

RUN 7: 493 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 6 | 16 | 0.5 |
| 9 | '' | 0.4 |
| 18 | 16 | 0.4 |
| 21 | 53 | 1.3 |
| 29 | 46 | 1.1 |
| 38 | 87 | 2.3 |
| 41 | 55 | 1.5 |
| **Totals:** 7 | 280 | 7.4 |

RUN 9: 436 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 344 | 116 | 3. 1 |
| 348 | 108 | 2.4 |
| 373 | 11 | 0.3 |
| 383 | 29 | 0.7 |
| 386 | 79 | 2.2 |
| 395 | 207 | 5..6 |
| 401 | 168 | 4.4 |
| 404 | 103 | 3.0 |
| 408 | 24 | 0.4 |
| 411 | 336 | S. 9 |
| 413 | 29 | 1. 1 |
| 417 | 116 | 3.5 |
| 419 | 28 | 0.7 |
| 421 | 102 | 2.6 |
| 426 | 117 | 3.2 |
| 430 | 68 | 1.9 |
| 434 | 203 | 5. 1 |
| 439 | 69 | 2.0 |
| 438 | 171 | 4.3 |
| 441 | 292 | 6.8 |
| 449 | 219 | 5.9 |
| 447 | 134 | 3. 8 |
| 44a | 200 | 5.1 |
| 490 | 378 | 9. 1 |
| 431 | 151 | 3.6 |
| 452 | 205 | 5.2 |
| 454 | 80 | 2.5 |
| 455 | 11 | 0.4 |
| 456 | 88 | 2.3 |
| 437 | 353 | 9.0 |
| 4s0 | 1'93 | 6.4 |
| 459 | 207 | 5.3 |
| 460 | 326 | S. 1 |
| 461 | 86 | 2.9 |
| 462 | 47 | 1.5 |
| 464 | 185 | 4.9 |
| 465 | 110 | 2.3 |
| 466 | 204 | 5.3 |
| 467 | 147 | 3. 5 |
| 468 | 492 | 13.0 |
| 469 | 68 | 1.6 |
| 470 | 252 | 6.7 |
| 471 | 510 | 13.4 |
| 472 | 213 | 6.6 |
| 473 | 130 | 3.6 |
| 474 | 37 | 0.9 |
| 479 | 140 | 3.2 |
| 476 | 22 | 0.5 |
| 477 | 69 | 1.9 |
| 479 | 194 | 5. 0 |
| 480 | i 32 | 3.7 |
| 481 | 161 | 4.7 |
| 482 | 62 | 1.6 |
| 483 | 13? | 3. 8 |
| 404 | 173 | 4.4 |
| 489 | 207 | 5.4 |
| 4136 | 35 | 1. 1 |
| 488 | 254 | 7. 1 |
| 4a? | 4s | 0.9 |
| 493 | 44 | 1. 1 |
| 494 | 168 | 4.5 |
| 499 | 93 | 2.6 |
| 497 | 221 | S. 8 |
| 500 | 231 | 9.9 |
| Totals: 64 | 9812 | 258.4 |

RUN 12: 495 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 8 | 109 | 2.7 |
| 12 | 133 | 3.8 |
| 13 | 123 | 2.9 |
| 14 | 54 | 1.8 |
| 16 | 76 | 2.4 |
| Totals: 5 | 495 | 13.7 |

RUN 15: 498 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 449 | 62 | 1.8 |
| 465 | 67 | 1.6 |
| Totals: 2 | 129 | 3.4 |

RUN 17: 499 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 51 | 256 | 6.2 |
| Totals: 1 | 25A | 6.2 |

RUN 18: 496 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 308 | 90 | 2.2 |
| 324 | 107 | 2.9 |
| 471 | 201 | 5.1 |
| 475 | 68 | 1.8 |
| Totals: 4 | 466 | 12.0 |

RUN 20: 391 points from a total of S00 points did not hit oil

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 369 | 145 | 4.1 |
| 373 | 221 | 5.8 |
| 374 | 34 | 0.8 |
| 375 | 46 | 1.2 |
| 378 | 132 | 3 2 |
| 379 | 339 | 8.6 |
| 381 | 118 | 2.9 |
| 322 | 324 | 8.9 |
| 383 | 710 | 5.6 |
| 385 | 134 | 3.6 |
| 386 | 38 | 1.3 |
| 387 | 121 | 3.0 |
| 388 | 215 | 5.9 |
| 393 | 178 | 4.8 |
| 395 | 215 | 4.3 |
| 396 | 89 | 2.2 |
| 399 | 253 | 7.1 |
| 402 | 151 | 4.1 |
| 403 | 07 | 2 2 |
| 404 | 138 | 3.6 |
| 405 | 7? | 2.3 |
| 406 | 127 | 3.4 |
| 407 | 257 | 7.1 |
| 40s | 268 | b.7 |
| 409 | 23? | 6.7 |
| 410 | 82 | 2.1 |
| 411 | 289 | b.4 |
| ●1Z | 415 | 10.7 |
| 413 | 371 | 9.3 |
| 414 | 139 | 4.2 |
| 415 | 71 | 1.b |
| 416 | ▫? | 2 6 |
| 417 | 421 | 10.3 |
| 419 | 1 b? | 4.2 |
| 420 | 315 | 8.3 |
| 421 | 17 | 0..5 |
| 423 | 463 | 11.7 |
| 424 | 142 | 3 3 |
| 425 | 172 | 4.0 |
| 427 | 170 | 4.9 |
| 430 | 228 | s.4 |
| 431 | 179 | 4.8 |
| 432 | 115 | 2.9 |
| 433 | 319 | 8.1 |
| 434 | 508 | 13.b |
| 435 | 296 | 7.2 |
| 436 | 185 | 4.9 |
| 437 | 374 | ?.9 |
| 438 | 171 | 4.9 |
| 439 | 115 | 3.3 |
| 440 | 486 | 12.6 |
| 441 | 89 | 2.8 |
| 442 | 230 | 6.4 |
| 443 | 215 | 5.2 |
| 444 | 192 | 5.3 |
| 445 | 148 | 4.0 |
| 446 | 266 | h.7 |
| 447 | 157 | 4.3 |
| 449 | 1%5 | 5.0 |
| 449 | 249 | 7 7 |
| 430 | 432 | 11.4 |
| 451 | 329 | 8.1 |
| 452 | 242 | 6.6 |
| 453 | 81 | 3.0 |
| 454 | 305 | 7 4 |
| 455 | 254 | 6.1 |
| 456 | 275 | 7 4 |
| 497 | 228 | 5.9 |
| 459 | 132 | 3 2 |
| 459 | 55 | 1 4 |
| 460 | 1 82 | 4.8 |
| 461 | 201 | 5 5 |
| 4.52 | 222 | 6.5 |
| 4 6 3 | 171 | 4 4 |
| 464 | 89 | 2.5 |
| 465 | 480 | 12.0 |
| 466 | 95 | 2.6 |
| 467 | 325 | e.7 |
| 468 | 246 | 6.9 |
| 469 | 207 | 5.2 |
| 470 | 258 | 6.4 |
| 471 | 172 | 4.4 |
| 472 | 465 | 12 4 |
| 474 | 125 | 3.7 |
| 475 | 59 | 1.5 |
| 476 | 179 | 4.6 |
| 477 | 347 | 9.2 |
| 478 | 312 | s.0 |
| 47? | 312 | 7.9 |
| 480 | 278 | 7.4 |
| 481 | 341 | 8.8 |
| 482 | 63 | 2.1 |
| 493 | 343 | 9.2 |
| 484 | 65 | 1,9 |
| 465 | 407 | 10.9 |
| 486 | I 99 | 4.6 |
| 4s7 | 192 | 4.3 |
| 408 | 166 | 4.5 |
| 489 | 101 | 2.5 |
| 490 | 246 | 6.9 |
| 491 | 130 | 2.7 |
| 492 | 10s | 2.7 |
| 493 | 85 | 2.6 |
| 494 | 67 | 1.7 |
| 495 | 88 | 2.4 |
| 496 | 164 | 4.3 |
| 497 | 310 | 7.6 |
| 498 | 182 | 4.6 |
| 499 | 105 | 2.s |
| Totals: 109 | 22627 | 590.W |

RUN 24: 3'73 points from a total of 590 points did not hit oil

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 40 | 91 | 3.2 |
| 43 | ?19 | 9.6 |
| 44 | 34 | 1.2 |
| 46 | 84 | 1.8 |
| 47 | 78 | 2.4 |
| 48 | 95 | 2 2 |
| 50 | 320 | 8.5 |
| 32 | 111 | 3 1 |
| 56 | 143 | 3.9 |
| 57 | ?79 | 7 3 |
| 59 | 138 | 3.7 |
| 60 | 321 | 7.8 |
| 61 | 129 | 2.7 |
| 62 | ?49 | b. 6 |
| 67 | 25 | 0.6 |
| 68 | 194 | 3.8 |
| 69 | 399 | 10 4 |
| 71 | 699 | 18.1 |
| 72 | 1 02 | 2 4 |
| 75 | ?57 | 6.6 |
| 76 | 173 | 4.7 |
| 77 | 368 | 9 2 |
| so | 126 | 2 9 |
| 81 | 69 | 1.3 |
| 732 | 172 | 4.4 |
| 83 | 253 | 6.9 |
| 85 | 149 | 3.5 |
| 86 | 168 | 4.2 |
| 88 | 259 | & 4 |
| El? | 102 | 2.9 |
| 90 | 74 | 1.9 |
| 91 | 168 | 3.7 |
| 92 | so | 1 6 |
| '94 | 36 | 0.9 |
| 99 | 143 | 4.0 |
| 96 | 144 | 3.7 |
| ?7 | 116 | 2.8 |
| 98 | 98 | 2 6 |
| 99 | 89 | 2.5 |
| 100 | 10s | 2.6 |
| 102 | I 22 | 3.0 |
| 104 | 97 | 2.3 |
| 107 | 264 | 7 3 |
| 108 | 312 | 8.5 |
| 107 | 246 | 6.2 |
| 110 | 227 | 6.2 |
| 111 | 171 | 4.9 |
| 112 | a | 0.3 |
| 114 | 9a | 2.2 |
| 116 | 117 | 2.9 |
| 118 | 109 | 3.2 |
| 121 | 70 | 1.5 |
| 122 | 41 | 1.3 |
| 125 | 103 | 3.0 |
| 128 | 221 | 5.5 |
| 130 | 81 | 1.8 |
| 131 | 77 | 2 1 |
| 132 | 1□3 | 4 3 |
| 13s | 42 | 1.3 |
| 136 | 156 | 5 1 |
| 137 | 170 | 4 9 |
| 13s | 296 | 7 3 |
| 13? | 12? | 3 9 |
| 141 | 110 | 2 9 |
| 142 | 295 | 7.3 |
| 143 | 143 | 4.0 |
| 144 | 69 | 2.4 |
| 14s | 69 | 1.□ |
| 153 | 115 | 2 6 |
| 154 | 55 | 1 4 |
| 155 | 42 | 1.2 |
| 157 | 22 | 0 4 |
| 158 | 104 | 2.0 |
| 15? | 137 | 3.7 |
| 1ho | 16 | 0.4 |
| 161 | 83 | 1.8 |
| 164 | 281 | 7.7 |
| 165 | 20 | 0.5 |
| 173 | 417 | 10.8 |
| 174 | 65 | 1.8 |
| 17s | ?24 | .6.3 |
| 176 | 107 | 3.0 |
| 178 | 77 | 2.3 |
| 181 | 40 | 1.0 |
| 182 | 27 | 0.4 |
| 183 | 90 | 2.5 |
| 184 | 116 | 3.2 |
| 1S33 | 51 | 1.3 |
| 106 | 112 | 2.6 |
| 187 | 27 | 0.4 |
| 190 | 73 | 2.1 |
| 192 | 110 | 2.6 |
| 194 | 93 | 2 4 |
| 195 | 42 | 1.0 |
| 196 | 122 | 3.4 |
| 197 | 98 | 2.7 |
| 198 | 94 | 2.3 |
| 202 | 91 | 2.6 |
| 209 | 70 | 1.8 |
| 212 | 88 | 2.9 |
| 214 | 72 | 1.8 |
| 219 | 56 | 1 6 |
| 217 | 107 | 2 s |
| 218 | 56 | 1.5 |
| 2.19 | 327 | 7.□ |
| 220 | 272 | 7 3 |
| 22.2 | 116 | 3.2 |
| Totals: 107 | 14?23 | 389 5 |

RUN 25: 476 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 171 | 65 | 1.6 |
| 174 | 129 | 3.4 |
| 2G0 | 35 | 1.1 |
| 209 | 107 | 2.4 |
| 215 | 74 | 2.1 |
| 227 | 39 | 1.1 |
| 228 | 85 | 2.5 |
| 229 | 13& | 2.7 |
| 230 | 59 | 1.2 |
| 233 | 122 | 2.9 |
| 238 | 234 | 6.2 |
| 239 | 164 | 4, 1 |
| 240 | 173 | 4.1 |
| 241 | 178 | 4.9 |
| 242 | 191 | 4.9 |
| 247 | 312 | 7.5 |
| 257 | 104 | 2.5 |
| 260 | 161 | 3.9 |
| 2151 | 196 | 5.2 |
| 262 | 120 | 3.5 |
| 264 | 175 | 4.8 |
| 268 | 231 | 6.3 |
| 269 | 192 | 5.3 |
| 272 | 148 | 3.6 |
| Totals: 24 | 3430 | 87.0 |

Table 1).2 Number of surfacings in oil and time in oiled water for individual gray whale points for each spill scenario at St. George site 1 (autumn spills) resulting in whale-oil encounters. Values are calculated at 10 days after the last oil release. Note that results are presented for whale points: each whale point represents 34 gray whales.

RUN 5: 477 points from a total of 500 points did not hit oil.

| | Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|---|
| | 44 | 53 | 1.3 |
| | 47 | 66 | 2. 1 |
| | 63 | 48 | 1.4 |
| | 99 | 74 | 1. 8 |
| | 124 | 123 | 3.2 |
| | 131 | 7 | c). 2 |
| | 175 | 69 | 1.7 |
| | 193 | 214 | 6. 1 |
| | 196 | 72 | 2. 4 |
| | 208 | 52 | 1.6 |
| | 232 | 82 | 2.2 |
| | 246 | 17 | c). 4 |
| | 265 | 367 | 9. 1 |
| | 294 | 86 | 2.3 |
| | 299 | 15 | 0.7 |
| | 319 | 11 | 0. 4 |
| | 346 | 62 | 1.9 |
| | 350 | 73 | 1.8 |
| | 358 | 54 | 1. 5 |
| | 394 | 113 | 2. 6 |
| | 405 | 51 | 1. 1 |
| | 414 | 31 | 0.7 |
| | 489 | 67 | 1.7 |
| Totals: | 23 | 1 807 | 48.4 |

RUN 6: 475 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 33 | 244 | 6.5 |
| 34 | 149 | 3.7 |
| 47 | 50 | 1.3 |
| 57 | 109 | 2.8 |
| 66 | 106 | 3.2 |
| 84 | 34 | 0.a |
| 114 | 192 | 4.6 |
| 123 | 146 | 3.5 |
| 133 | 6 | 0.1 |
| 134 | 164 | 4.2 |
| 139 | 176 | 4.4 |
| 144 | 28 | 0.5 |
| 152 | 70 | 2.3 |
| 133 | 174 | 4.7 |
| 185 | 88 | 2.6 |
| 200 | 57 | 2.1 |
| 212 | 184 | 4.4 |
| 215 | 135 | 3.8 |
| 237 | 10 | 0.3 |
| 245 | 24 | 0.6 |
| 274 | 207 | 5.2 |
| 270 | 215 | 5.9 |
| 322 | 132 | 2.6 |
| 3i34 | 275 | 6.6 |
| 400 | 61 | 1.8 |
| Totals: 25 | 3036 | 78.4 |

RUN 8: 442 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 33 | 99 | 1.9 |
| 35 | 27 | 0.7 |
| 74 | 43 | 1.4 |
| B? | 64 | 2.2 |
| ?4 | 14 | 0.4 |
| 102 | 111 | 3.3 |
| 107 | 95 | 2.7 |
| 114 | 160 | 4.1 |
| 122 | 89 | 2.0 |
| 126 | 119 | 3.4 |
| 13a | 28 | 0.7 |
| 173 | 11 | 0.4 |
| 177 | 99 | 2.6 |
| 187 | 97 | 2.0 |
| 229 | 141 | 3.7 |
| 257 | 9 | 0.1 |
| 2S9 | 98 | 2.7 |
| 270 | 133 | 4.0 |
| 274 | 61 | 1.9 |
| 276 | 39 | 1.1 |
| 277 | 120 | 2.7 |
| 278 | ?7 | 2.3 |
| 317 | 15 | 0.5 |
| 321 | 140 | 2.a |
| 324 | 69 | 1.9 |
| 333 | 61 | 1.7 |
| 333 | 80 | 1.7 |
| 339 | 109 | 2.8 |
| 342 | 66 | .2.0 |
| 347 | 72 | 2.1 |
| 351 | 111 | 2.6 |
| 3S2 | 152 | 3.7 |
| 361 | 80 | 2.3 |
| 367 | 104 | 2.4 |
| 376 | 52 | 1.6 |
| 381 | 126 | 3.3 |
| 383 | 113 | 2.9 |
| 386 | 7a | 2.4 |
| 387 | 64 | 2.0 |
| 394 | 26 | 0.5 |
| 402 | 72 | 2.2 |
| 414 | 55 | 1.2 |
| 419 | 32 | 0.9 |
| 421 | 48 | 1.4 |
| 426 | 143 | 3.9 |
| 440 | 41 | 1.1 |
| 448 | 164 | 3.9 |
| 492 | 64 | 1.8 |
| 493 | 89 | 2.0 |
| 458 | 140 | 3.5 |
| 459 | 100 | 2.7 |
| 479 | 111 | 3.0 |
| 476 | 48 | 1.1 |
| 4s0 | 116 | 3.4 |
| 486 | 47 | 1.4 |
| 490 | 36 | 0.7 |
| 493 | 104 | 3.3 |
| 498 | 48 | 1.2 |
| Totals: 5a | 4726 | 124.6 |

RUN 9: 388 points from a total of 500 points did not hit oil

| Wh e p· # | # of hits | Time in oil (hrs) |
|---|---|---|
| 11 | 185 | 5.2 |
| 34 | 174 | 4.6 |
| 48 | 56 | 1.4 |
| 43 | 249 | 5.9 |
| 45 | 49 | 1.5 |
| 53 | 194 | 5.0 |
| 54 | 5 | 0.0 |
| 75 | 107 | 2 7 |
| 83 | 99 | 2 5 |
| 89 | 42 | 1. 2 |
| 93 | 78 | 1.7 |
| 93 | 165 | 4.6 |
| 94 | 35 | 1.0 |
| 92 | 127 | 2 9 |
| 93 | 121 | 2 9 |
| 96 | 28 | 0.7 |
| 07 | 131 | 3 0 |
| 08 | 185 | 4.2 |
| 19 | 49 | 1.4 |
| 12 | 307 | 7.8 |
| 14 | 66 | 1.8 |
| 20 | 16 | 0. 4 |
| 38 | 175 | 4. 3 |
| 39 | 123 | 2 3. 9 |
| 44 | 122 | 4. 1 |
| 44 | 177 | 6. 8 |
| 149 | 256 | 3. 3 |
| 140 | 115 | 5. 0 |
| 141 | 199 | 3. 2 |
| 154 | 145 | 2. 7 |
| 157 | 97 | 5 5 |
| 270 | 219 | 2. 8 |
| 283 | 87 | 5.1 |
| 280 | 181 | 5.1 |
| 283 | 201 | 4. 3 |
| 294 | 153 | 5. 4 |
| 297 | 225 | 7. 6 |
| 202 | 267 | 4. 4 |
| 213 | 163 | 4. 8 |
| 212 | 173 | 2. 3 |
| 212 | 102 | 7 |
| 216 | 152 | 4 1 |
| 227 | 144 | 3. 9 |
| 229 | 137 | 3. 4 |
| 220 | 117 | 3. 3 |
| 235 | 117 | 3. 0 |
| 232 | 47 | 1. 3 |
| 236 | 7 | 0. 2 |
| 249 | 16 | 0. 3 |
| 243 | 215 | 5 0 |
| 245 | 92 | 2. 7 |
| 256 | 19 | 0. 8 |
| 250 | 167 | 5. 1 |
| 25. | 82 | 2. 3 |
| 253 | 142 | 3 6 |
| 2.6 | 158 | 4. 0 |
| 267 | 90 | 2 6 |
| 260 | 254 | 6. 3 |
| 261 | 164 | 4. 1 |
| 274 | 174 | 5. 4 |
| 271 | 90 | 2 6 |
| 281 | 137 | 3 3 |
| 287 | 221 | 4. 9 |
| 350 | 69 | 1. 9 |
| 354 | 268 | 6. 7 |
| 359 | 75 | 2 4 |
| 390 | 81 | 1. 9 |
| 391 | 218 | 5. 5 |
| 305 | 16 | 0 5 |
| 317 | 115 | 3 |
| 310 | 10 | 0 1 |
| 324 | 148 | 3 3 |
| 321 | 47 | 1 7 |
| 322 | 157 | 4 4 |
| 335 | 29 | 1 0 |
| 331 | 65 | 1 1 |
| 348 | 157 | 4 7 |
| 343 | 227 | 6 7 |
| 345 | 217 | 5 0 |
| 356 | 141 | 3 8 |
| 358 | 164 | 4 0 |
| 369 | 139 | 4. 1 |
| 361 | 193 | 5. 0 |
| 362 | 52 | 1. 4 |
| 363 | 136 | 3. 5 |
| 364 | 42 | 1. 7 |
| 366 | 6 | 0 2 |
| 367 | 51 | 1. 3 |
| 368 | 100 | 2 6 |
| 369 | 106 | 2. 6 |
| 375 | 30 | 1. 0 |
| 380 | 300 | 6 7 |
| 383 | 135 | 3. 7 |
| 485 | 227 | 6. 3 |
| 486 | 59 | 1. 4 |
| 494 | 114 | 2 7 |
| 403 | 162 | 4. 9 |
| 405 | 174 | 4. 6 |
| 414 | 68 | 1. 7 |
| 415 | 230 | 6 1 |
| 416 | 27 | 0. 7 |
| 420 | 58 | 6 |
| 424 | 199 | 1 7 |
| 435 | 180 | 4 0 |
| 438 | 237 | 6 3 |
| 442 | 86 | 2 0 |
| 443 | 222 | 6 0 |
| 447 | 222 | 5 6 |
| 477 | 58 | 2 0 |
| 480 | 189 | 5 0 |
| 482 | 92 | 2.2 |
| 496 | 176 | 5.0 |
| Totals: 112 | 14667 | 384.4 |

RUN 14: 499 points from a total of points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 262 | 177 | 4.1 |
| Totals: 1 | 177 | 4.1 |

RUN 18: 439 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 2 | 120 | 3.3 |
| 1s | 103 | 2.2 |
| 22 | 73 | 2.3 |
| 23 | 152 | 3.7 |
| 32 | 185 | 4.8 |
| 34 | 293 | 6.8 |
| 35 | 181 | 4.9 |
| 36 | 126 | 3.6 |
| 47 | 173 | 4.b |
| 66 | 96 | 2.9 |
| 72 | 234 | 6.5 |
| 74 | 38 | 1.s |
| 79 | 97 | 2.3 |
| 85 | 87 | 2.1 |
| 92 | 237 | 5.8 |
| 102 | 223 | 5.7 |
| 104 | 140 | 4.2 |
| 119 | 20 | 0.5 |
| 123 | 8 | 0.2 |
| 133 | 14 | 0.4 |
| 138 | 132 | 2.9 |
| 144 | 91 | 2.5 |
| 147 | 149 | 4.1 |
| 153 | 208 | 5.1 |
| 1.52 | 278 | 6.9 |
| 104 | 151 | 4.2 |
| 204 | 74 | 1.8 |
| 218 | 229 | 5.5 |
| 224 | 180 | 4.6 |
| 230 | 138 | 3.3 |
| 232 | 164 | 5.0 |
| 237 | 191 | 5.4 |
| 246 | 10 | 0.3 |
| 249 | 69 | 1.6 |
| 251 | 146 | 4.2 |
| 2.43 | 31 | 1.0 |
| 265 | 136 | 3.3 |
| 270 | 13 | 0.2 |
| 270 | 60 | 2.4 |
| 283 | 131 | 3.3 |
| 284 | 14 | 0.4 |
| 285 | 108 | 2.6 |
| 286 | 108 | 2.4 |
| 287 | 238 | 6.2 |
| 295 | 135 | 4.0 |
| 297 | 11 | 0.4 |
| 307 | 200 | 4.9 |
| 310 | 42 | 1.0 |
| 318 | 81 | 2.0 |
| 322 | 251 | 6.3 |
| 338 | 95 | 2.1 |
| 341 | 117 | 2.7 |
| 348 | 284 | 7.6 |
| 358 | 31 | 1.0 |
| 383 | 186 | 5.0 |
| 400 | 34 | 0.7 |
| 416 | 9 | 0.3 |
| 438 | 204 | 5.1 |
| 44s | 97 | 3.2 |
| 479 | 162 | 5.& |
| 500 | 108 | 2.7 |
| Totals: 61 | 7732 | 201.8 |

RUN 20: 423 points from a total of 500 points did not hit oil.

| Whale pt ID # | # of hits | Time in oil (hrs) |
|---|---|---|
| 3 | 30 | 0.8 |
| 5 | 70 | 1.7 |
| 10 | 89 | 2.0 |
| 16 | 19s | 5.2 |
| 20 | 57 | 1.3 |
| 21 | 69 | 1.5 |
| 24 | 77 | 2.2 |
| 28 | 14 | 0.6 |
| 34 | 130 | 3.8 |
| 39 | 111 | 2.9 |
| 37 | 54 | 1.4 |
| 49 | 90 | 2.7 |
| 47 | 46 | t.4 |
| 57 | 48 | 1.2 |
| 61 | 644 | 17.4 |
| 64 | 71 | 1.9 |
| 6S | 99 | 2.9 |
| 70 | 55 | 1.3 |
| 79 | 109 | 3.1 |
| 76 | 335 | a.6 |
| 78 | 79 | 2.1 |
| 83 | 29 | 0.7 |
| 88 | 92 | 2.7 |
| 93 | 39 | 0.B |
| 100 | 86 | 1.7 |
| 106 | 122 | 3.4 |
| 107 | 67 | 1.7 |
| 108 | 91 | 2.6 |
| 116 | 164 | 4.3 |
| 118 | 139 | 3.1 |
| 120 | 23 | 0.7 |
| 129 | 24 | 0.4 |
| 138 | 74 | 1.8 |
| 146 | 26 | 0.5 |
| 151 | 57 | 1.7 |
| 152 | 82 | 2.2 |
| 153 | 37 | 0.9 |
| 160 | 24 | 0.3 |
| 163 | 76 | 2.1 |
| 178 | 120 | 2.6 |
| 179 | 86 | 3.2 |
| 180 | 101 | 2.4 |
| 182 | 117 | 3.0 |
| 1s3 | 47 | 1.5 |
| 194 | 144 | 3.9 |
| 216 | 72 | 1.9 |
| 220 | 102 | 2.6 |
| 221 | 4a | 1.3 |
| 227 | 60 | 1 . 5 |
| 235 | 34 | 1.1 |
| 241 | 32 | 0.7 |
| 244 | 103 | 2.4 |
| 247 | 14 | 0.6 |
| 262 | 122 | 3.2 |
| 279 | 67 | 1.9 |
| 2S4 | B7 | 1.5 |
| 293 | 118 | 2.6 |
| 297 | 148 | 3.9 |
| 320 | 94 | 2.7 |
| 323 | 34 | 0.7 |
| 326 | 72 | 1.8 |
| 327 | 113 | 3.0 |
| 338 | 224 | s.9 |
| 341 | 103 | 2.3 |
| 358 | 45 | 1.7 |
| 399 | 68 | 1.5 |
| 396 | 126 | 3.4 |
| 410 | 30 | 0.7 |
| 412 | 25 | 0.B |
| 424 | 33 | 0.6 |
| 431 | 29 | 0.7 |
| 43s | 108 | 2.6 |
| 43a | 30 | 0.6 |
| 439 | 75 | 1.8 |
| 495 | 141 | 3.3 |
| 4.51 | 59 | 1.7 |
| 482 | 110 | 2.6 |
| Totals: 77 | 6880 | 177.9 |